6-6-2017

Forge 2.0 Clean Burning Cook Stove

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Forge 2.0: Clean Burning Cook Stove

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

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6/15/2017

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FORGE 2.0:
CLEAN BURNING COOK STOVE

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SENIOR DESIGN PROJECT REPORT

Submitted to
the Department of Mechanical Engineering

of

SANTA CLARA UNIVERSITY

in Partial Fulfillment of the Requirements
for the degree of
Bachelor of Science in Mechanical Engineering

Santa Clara, California

June 6th, 2017

ABSTRACT

Team Forge 2.0 is a team of mechanical engineers that has designed, modified, and manufactured a cook stove that creates a clean burn in order to help relieve respiratory disease and harmful environmental impacts resulting from the combustion of biomass in developing nations. The stove is developed specifically for developing communities in Nicaragua that still use traditional cooking methods which contribute to premature deaths due to respiratory illness. The designed product is a cylindrical cooking device that has a unique air flow system which optimizes the gasification process. Gasification is the process in which gas released from the primary combustion of biomass is reignited, creating a more complete combustion and thus reducing harmful emissions compared to a traditional wood fire. From testing with a previous design team's prototype, observations were made which led to the implementation of an air flow system which could be regulated manually. The air flow regulator is a mechanical attachment that allows users to adjust the air flow in the stove to prolong the gasification process; this modification helps the stove maintain gasification throughout usage, and resulted in an 8% reduction of particulate matter in the stove's exhaust compared to the most recent design.

ACKNOWLEDGEMENTS

Team Forge 2.0 would like to thank all those involved with helping us complete our project. This project has been very challenging and forced team members to apply all the engineering principles that we have learned at Santa Clara University. We would like to thank Dr. Robert Marks and Dr. Timothy Hight for constantly working with us on this project; without their guidance and advice we would not have been able to complete our project.

We would also like to thank Ms. Susan Kinne, co-founder of Grupo Fenix, for acting as our main contact in Nicaragua. Ms. Kinne was able to answer all of our questions regarding life in Nicaragua and played a key role in helping us identify a problem, design a solution, and understand life in Nicaragua. We would like to thank Dr. Jesica Fernández for translating our user manual into Spanish and enabling us to properly communicate the workings of our stove to our Nicaraguan customers. We would also like to thank PWP Manufacturing for machining the prototype and giving estimates on prices for mass production. The Environmental Science and Studies Department here at Santa Clara University also provided us with testing equipment which was necessary for the evaluation of our design's performance.

Finally we would like to thank Santa Clara School of Engineering for providing funding for our project to make our design possible. Santa Clara University has given us all the necessary education, funding, and support that gave us the opportunity for our design team to produce the best possible project we could.

We thank everyone and anyone who helped us throughout the process, your contributions are appreciated and not forgotten.

-Team Forge 2.0

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Chapter 1 – Introduction

1.1 Background

This will be the fourth year a senior design team attempts to create a clean burning cook stove for developing nations. The most recent design team, known as Forge, achieved gasification, which is the burning of smoke as well as wood, thus producing a cleaner burn; however, the degree of gaseous pollutants and particulate matter eliminated was not tested. Forge implemented a thermoelectric system which would charge mobile devices using the heat created by the fire in an attempt to provide off-grid power for people in developing countries.[1] The figures below show cook stoves designed by past design teams.

Figure 1.1: Cook stove designed by Team Forge (2016).

[1] FORGE Thesis.

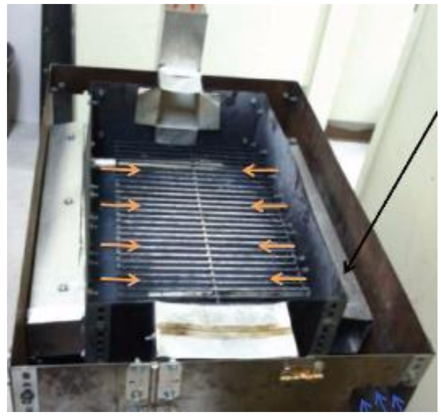

Figure 1.2: Cook stove designed by Team Matador (2014).

The present design team sought to improve the gasification effect achieved by the stove, thus eliminating harmful emissions created by it and reducing the amount of fuel needed. This was done by modifying the air flow system of Forge's prototype cook stove. Since the purpose of the project was to build a clean burning cook stove for developing nations, the community of Totogalpa in Nicaragua was chosen to be the target market for Team Forge 2.0's product.

Rural Nicaragua was chosen to be the target market primarily because of the impoverished nature of the community, the relative proximity of the region to Santa Clara compared to other places where this product would provide socioeconomic benefit, and because previous design teams had made contacts in the Totogalpa region. Through contact with Susan Kinne, the co-founder of Grupo Fenix, Team Forge 2.0 was able to gain a better understanding of how the people in the target market live.

Grupo Fenix is an organization working with appropriate and innovative technologies to improve the quality of life for rural Nicaraguan families and communities in the areas of health, education, employment, environment, and gender equality. Team Forge 2.0 learned that in Nicaragua, locals traditionally use firewood stoves of clay or brick, with a hole in the top for a pot or pan to be placed. These structures often do not have chimneys, and smoke residue accumulates on the kitchen walls, pots, pans, and most alarmingly, in the lungs of family members who cook together.[2] The performance achieved through gasification by this design team's cook stove reduced the pollutants created by a wood fire, making it safer to use in the

[2] Kinne, Susan.

home and better for the environment. It also decreased the amount of fuel needed for a given cooking session, allowing users to spend less time and energy on fuel gathering.

The objective of this cook stove is to safely and reliably reduce the pollution produced when cooking food, allowing families to use the device in their homes without the addition of ventilation systems. Doing so would have a significant impact on the people of Nicaragua by reducing the amount of respiratory disease and premature deaths. The gasification effect achieved by this stove would additionally reduce the negative environmental impact relative to existing cook stoves due to the decrease in gaseous emissions created during the cooking process.

1.2 Environmental Field Literature

Anaerobic digestion is a proposed solution to producing biogas for combustion as it produces much less carbon dioxide than many other methods. Since wood burning stoves are responsible for many health and environmental problems all over the world, alternatives are explored by the authors of the paper entitled *Economic and Environmental Analysis of Farm-Scale Biodigesters to Produce Energy for Kitchen Stove Use*. The study tested biodigesters in various third world countries including Nicaragua. The result of this study, using techno-economic analysis and life cycle assessment, showed biodigesters are the most cost effective method. It was both more economical and more environmentally friendly than burning wood. However, they require so much water that anaerobic digestion may no longer be considered a sustainable method.[3] We used this information to help determine that gasification would be the best method to employ in a clean burning cooking for this specific application.

In a report by The Environment Department of The World Bank, titled *Household Cook stoves, Environment, Health and Climate Change: A New Look at an Old Problem*, the effects of traditional cooking methods in developing nations on various sustainability and social issues are explored. From an environmental standpoint, the burning of biomass is contributing to the rise in global temperatures. In developing nations, about 730 million tons of biomass are burned annually, which amounts to over 1 billion tons of CO_2 emitted into the atmosphere, which is

[3] Bartlett, Zachary P. et al.

equal to the amount of CO_2 emissions caused by biomass combustion for all purposes in developed nations.[4] The reduction of gaseous emissions resulting from the gasification process could help combat climate change if implemented in a cook stove that is used widely across developing nations.

1.3 Technical Field Literature

Optimization of gasification is one of this design team's highest priorities, however, it is a challenging process which has interested design engineers in the past. The article *Development of Small-Scale Gasification and Power Generation System for Woody Biomass* by Miki Taniguchi and Aiko Nishiyama explains how another team achieved gasification of biomass via a twofold process. The first stage is pyrolysis, the second is char gasification. Their results helped guide this design team in understanding the gasification process.

To explain the gasification process further, the following information comes from *Heat Generators with TLUD Gasifier for Generating Energy From Biomass With a Negative Balance of* CO_2 by Murad and Dragomir. Due to the continuous global warming it is evermore important to reduce the the CO_2 concentration in the atmosphere. Biomass is a renewable source of thermal energy which is easily converted into both mechanical and electrical energy. Burning wood and vegetal biomass has been used not only to generate thermal energy at high efficiencies, but it also has created high emissions of carbon monoxide and particulate matter into the atmosphere. Thermochemical biomass gasification is a process which converts biomass into combustible gas with high energy conversion efficiency and reduces the amount of gaseous and particulate emissions, thus the gas produced can burn cleanly as well as efficiently. The process begins when a biomass layer is placed within a combustion chamber through which air can pass from bottom to top. When the top layer of biomass is ignited, it continuously burns down as it is consumed by the fire. The heat radiated from combustion dries the top layer and it begins a fast pyrolysis process which releases volatiles, such as tar, that burn with air. This combustion of volatiles releases CO, CO_2, H_2, H_2O and CH_4 as well as tars (heavy hydrocarbons). Biomass itself is composed of 75% volatile and 25% fixed carbon. The fixed carbon does not go through

[4] The World Bank.

the gasification process, instead it becomes biochar. For higher temperatures there remains less biochar. In a well-insulated ceramic reactor, the amount of remaining biochar is, on average, less than 10% of the initial mass of the fuel. The continuous supply of air flow will then pass over the remaining biochar and chemically eliminate the remaining CO_2 in char gasification.[5]

Biochar can be used in a variety of ways once produced through gasification. The following information comes from IBI. Biochar is not to be confused with charcoal, as it is not used for fuel. Instead biochar is predominantly used as a soil enhancer and a biomass emission reducer.[6] As a soil enhancer, biochar enables soil to hold nutrients and increases soil fertility by neutralizing soil acids. Reusing the biochar as a soil enhancer not only reduces agricultural waste but also produces a clean source of renewable energy, in the form of gas or oil. According to IBI, biochar enhanced soils have shown higher crop yields during field trials in the tropics. Traditionally, Brazil and Japan have been known to utilize the positive effects of biochar enhancement.[7]

Biochar enables the long term enhancement of soil fertilization utilizing local materials in the form of biomass. One single application of biochar can provide multiple years of soil benefits. In developing countries, soil degradation is a persistent problem where biochar offers a solution for sustainable soil management.

The porous nature of biochar has the potential to house many microorganisms and improve the soil water-holding capacity while also holding carbon, energy and nutrients.[8] The addition of biochar reduces soil acidity with a negative charge which develops on its surface, the same charge that is responsible for retaining nutrients. Carbon is the main component of soil organic matter and helps give soil its water-retention capacity, its structure, and its fertility.[9] In addition, biochar mitigates climate change by sequestering carbon in soil where it remains for hundreds of thousands of years. This means that carbon and other harmful chemical compounds such as methane are used as integral components in soil and are prevented from being released into the atmosphere. Thus, biochar serves a dual purpose when added to soil.

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[5] Murad, Erol and Dragomir, Florian.
[6] *International Biochar Initiative.*
[7] *International Biochar Initiative.*
[8] Schwartz, Judith.
[9] Schwartz, Judith.

1.4 Project Objectives

In early 2017, the design team began preparing a prototype of the device, which was then extensively tested for five unknowns:

1. Level of pollutants in gases created by the woodfire.
2. Amount of heat created by the device.
3. Achievable temperature for the cooking surface and distribution.
4. Amount of pollutants eliminated by degree of gasification achieved.
5. Amount of time to achieve gasification.

Because the safety of the users was at the forefront of the design team's concerns, insulation within the device will be a primary concern to keep the temperature of the outer surface of the device as low as possible, to reduce the risk of injury to the user. In addition, the level of pollutants needed to be minimal compared to those produced by existing cooking methods and competing products in order to be competitive.

With the prototype completely built, the design team tested and modified components as necessary for the stove to achieve desired performance, which was benchmarked by the ability to produce a clean burn compared to other products and traditional methods of cooking. It was then necessary to look into possible manufacturing methods and distribution to the desired markets, so the device can have the largest impact possible in developing countries such as Nicaragua. The final goal of project will be achieved when the design team has a working cook stove implemented in Nicaragua.

Chapter 2 – Systems-Level Chapter

2.1 Customer Needs

According to the *World Health Organization*, three billion people cook their meals using open fires and simple stoves burning biomass (wood, animal dung and crop waste) and coal. Every year, four million premature deaths from illness are attributed to the household air pollution from cooking with solid fuels. More than 50% of premature deaths due to pneumonia among children under 5 are caused by the particulate matter (soot) inhaled from household air pollution.[10] These facts influenced the students who were part of Team Forge during the 2015-2016 academic year to attempt to build a cook stove that achieved gasification. Gasification is a phenomenon where the burning of wood or coal also results in the burning of the smoke released from the combustion process. The most notable, visible indicator of effective gasification is the lack of smoke exiting the chimney. Therefore, successful gasification could eliminate much of the pollution that families encounter when cooking inside their homes. Team Forge was able to achieve gasification to an unknown degree with their final product, so this design team focused on quantifying the reduction in emissions relative to traditional cooking methods and on improving upon these results.

Due to the remote location of Team Forge 2.0's potential users, contacting them without traveling to Nicaragua was nearly impossible. To remedy this, this design team utilized last year's contact, Susan Kinne, the co-founder of Grupo Fenix, to gather information regarding the customer needs this product aimed to fulfill.

From Ms. Kinne it was learned that there are 500 to 600 homes in the targeted community, Totogalpa, each of which have a wood burning stove. Potential users suffer from indoor cooking pollution from burning local biomass. Their existing stoves are wood-fired, with permanent brick or clay structures surrounding for heat insulation. The ventilation is minimal leading to soot-filled homes and respiratory illness. Users fuel the stove by picking firewood up off the ground, resulting in a fuel size between 1in and 2.5in in diameter. When possible, users cut old limbs from trees, but as the community grows, there are more people and fewer trees. Some cut green trees and let them dry for later use. Additionally, Ms. Kinne informed Team Forge 2.0 that the rainy season in Nicaragua forces the people to burn damp fuel.

Since the community is family oriented, extended families cook together every night, meaning a stove capable of cooking large amounts of food at once is necessary. Ms. Kinne confirmed that the community's meals consisted of mostly rice and beans, stews and soups, as well as chicken and beef. She told us tortillas are very common as well so a flat cooking surface would be also be necessary.

[10] *World Health Organization.*

Based on potential customers' needs, Team Forge 2.0 determined it was necessary to design an affordable, clean burning cook stove which quickly achieved consistent gasification when burning local biomass. The table below displays the environmental, social, and economical needs that Susan presented and this design team's proposed solutions.

Table 2.1: Customer needs hierarchy according to Susan Kinne of Grupo Fenix.

Rank	Type	Need	Why?	How to achieve?
1	Environmental	Clean burn	Estimated 4 million die from air pollution annually and the hierarchy in Nicaragua demands clean air	Air flow system which enables gasification
2	Social	Heat output	Families cook together daily in large quantities	Efficient heat transfer from fire to cooking surface
3	Economical	Food	Ability to cook meals for families is necessary for survival	Biomass burned to create enough heat to cook
4	Economical	Fuel	Impoverished countries community members must use cheap local fuel sources	Wood and local biomass are zero cost

2.2 System Level Requirements

Prioritizing customer needs based on information gathered from preliminary research of the problem definition allowed for the completion of a criterion matrix which ranked the importance of each aspect of the design. It was determined that the two most important features of the cook stove would be its ability to cook food and to reduce harmful emissions. Given the high temperatures achieved by a wood fire, the stove must be able to transfer that heat to a cooking surface. A material with the ability to withstand the temperatures incurred by gasification and with adequate thermal conductivity for the transfer of heat to the cooking surface via conduction was required for the stove.

In order to achieve a clean burn, thus reducing the amount of gaseous and particulate emissions relative to traditional cooking methods, the stove must allow for the process of gasification to occur. The system required to achieve this was the air flow system, which allowed gasification to occur quickly and consistently. For gasification to occur, the system must allow air to enter the stove. Inlets into the combustion chamber were necessary so air could enter and combine with the burning fuel, initiating the process of pyrolysis. Secondary inlets to the combustion chamber were necessary to allow fresh air to combine with the woodgas created by pyrolysis and reignite. An exit port was necessary to allow the exhaust to escape and heat the cooking surface by convection.

The final prototype has two sets of secondary inlets in the combustion chamber. In order to maximize the duration of gasification, it was necessary to design a mechanism which could allow for one set of secondary inlets to remain open while the other set was closed.

2.3 Physical Sketch with User Scenario

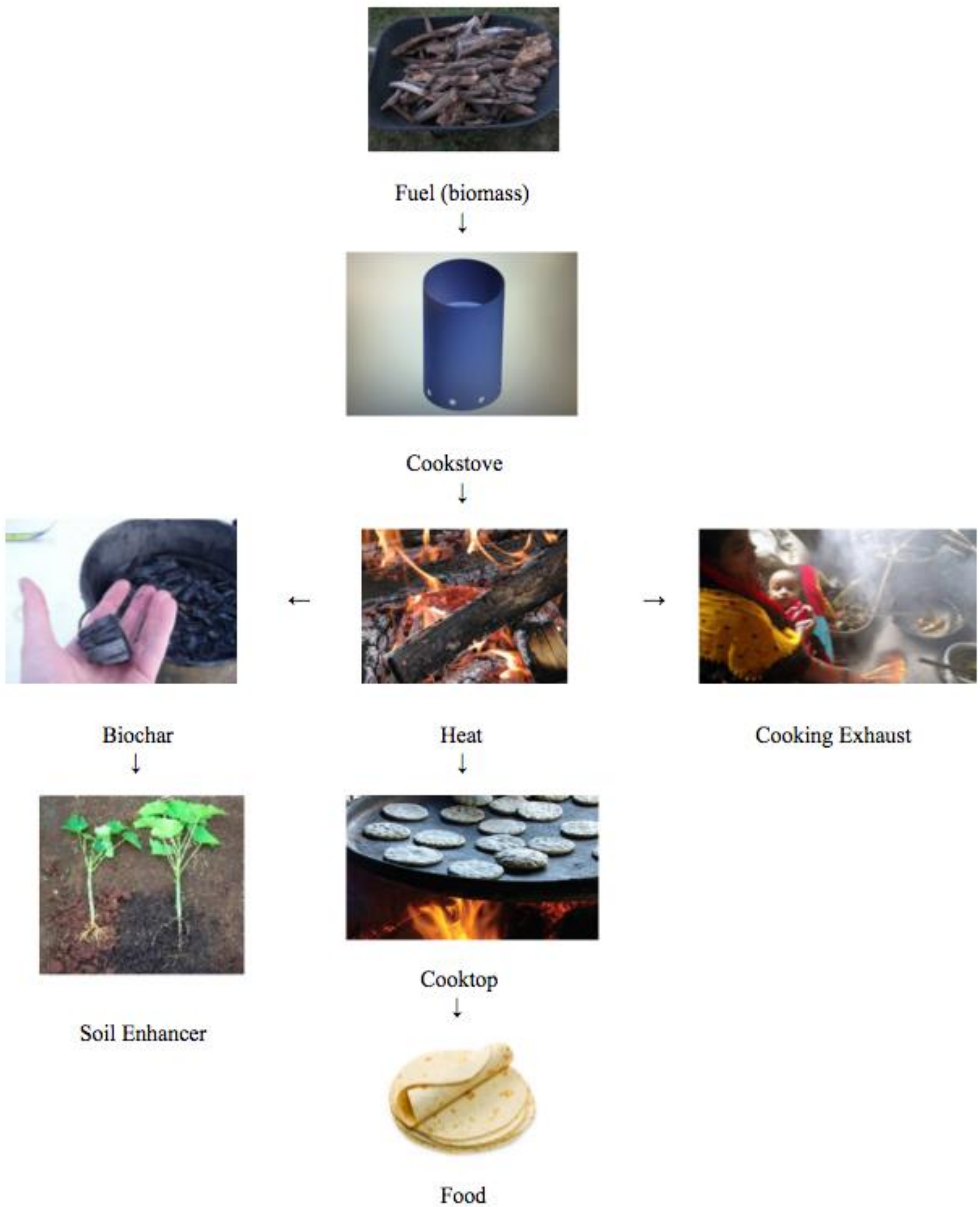

Figure 2.1: A pictorial representation of the stove's use.

People of Totogalpa, Nicaragua will use this stove to cook food each day with their families. They will first prepare the fire by gathering sticks and placing them inside the cook stove. They will then ignite the debris and thus begin the combustion process. The air flow system of the stove will allow it to reach high temperatures quickly, enabling gasification which will reduce gaseous emissions and particulate matter released into the atmosphere. Once the fuel burns down significantly, there will be only biochar remaining. This substance can be used as a soil enhancer by the target market, which consists of mostly rural farmers.[11] The users can keep adding debris to fuel the fire as long as they need to continue cooking, or stop adding debris and allow the fire to die and the gasification process to cease.

2.4 Functional Analysis

2.4.1 Functional Decomposition

The table below displays the primary functions as well as the subfunctions of the Forge 2.0 Cook Stove. The main functions include producing enough heat to cook meals as well as achieving a clean burn. The subfunction of the stove is producing a soil-enhancer byproduct.

Table 2.2: Main functions and subfunctions of the Forge 2.0 cook stove.

Main Functions	Cooking	The cookstove will produce enough heat on the cooking surface for families to be able to cook their meals
	Gasification	It will also produce a clean burn, ensuring families to inhale less pollution when cooking.
Subfunctions	Soil-enhancer	Remaining biochar can be used as a soil-enhancer.

[11] Kinne, Susan.

2.4.2 List of inputs and Outputs and Constraints

Team Forge 2.0’s cook stove operates with biomass as fuel and air as a reactant to produce heat. Since the combustion chamber of the stove is relatively small, the amount of reactants will be limited to within the inner shell walls, which are identified as the combustion chamber. This will in turn constrain the amount of heat output produced from the stove. With this production of heat also comes the production of harmful particulate matter and gaseous emissions which are released into the atmosphere and possibly the lungs of the user. The idea behind complete combustion is that there is just enough air present to react with the amount of fuel present to ensure there will be no other products other than water and carbon dioxide. Carbon monoxide still poses a problem, however, the gasification process will eliminate carbon monoxide, hydrocarbons, and tars, which present themselves as particulate matter.

Table 2.3: Constraints of inputs and outputs of the Forge 2.0 cook stove.

Input	Output	Constraints
Fuel (wood)	Heat	Increasing stove size would increase costs of production and implementation, so size and affordability constrain the amount of heat produced.
Air	Particulate Emissions	The amount of air that flows through the stove is also constrained due to the stove's specific geometry to maximize gasification, which constrains the amount of particulate emissions produced.

2.5 Benchmarking Results

Past senior design teams have attempted to design cook stoves for developing countries. These past projects were used to gauge our project’s scope of influence. In 2015, Team Matador’s cook stove focused primarily on electric generation driven by thermal energy, however, this proved to be difficult and left much room for improvement. The following year Forge continued Team Matador’s efforts amending their project significantly to include a clean burning feature to reduce harmful emissions while simultaneously generating electricity with the stove's heat output, again, leaving much room for improvement. Tabulated specifications and results from past projects can be viewed in Table 2.4.

Table 2.4: Past Senior Design Project Specifications

Past Senior Design Projects	Fuel	Weight	Maximum Heat Output	Voltage Output	Current Output	Air Pollution	Cost
Team Forge Cookstove (2016)	Solid biomass	20 lbs	4.91 kW	0.07 V	No data	No data	$847.37
Team Matador Cookstove (2015)	Solid biomass	99 lbs	No data	1.5 V - 2.5 V	No data	N/A	$320.00

Team Forge 2.0 decided to focus on the clean burning aspect of last year's stove designed by Forge. Since the Forge stove achieved visual gasification, but without the support of any quantitative data, Team Forge 2.0 focused on quantifying their results for comparisons alongside a proposed, amended design. Given that the inspiration for this project came from prior design teams' products, it was important that the new design exhibit improved performance as an emissions reducer relative to our predecessors as well as improvement in cost of production.

2.6 Key System-Level Issues and Tradeoffs

It was important to analyze and look at key system-level issues and tradeoffs in the design of the cook stove. The design of the cooking shell required a balance between cost and performance. A large stove would allow for a very large cooking surface, enabling users to cook with many pots at once, but the stove would sacrifice portability, and would cost more. While large stoves would cost more individually, the cost per person may actually be less than if small stoves were sold to the community members of Totogalpa, because less units would be needed. A smaller stove would allow for easier control of the gasification process. In a large stove, it would be more difficult to ensure all the woodgas reignites with fresh air. This could leave areas of unburned smoke, especially near the center of the stove, where the distance from the secondary air inlets would be greater than in a smaller stove. Additionally, a smaller cook stove would produce less emissions than a large cook stove.

Control of the air flow system was necessary for the optimization of the gasification process. A sophisticated control system in which an air flow regulation mechanism would adjust the secondary inlets automatically would improve the usability of the stove. However, this would also increase the cost of the cook stove, and decrease reliability, given the higher durability of a manually-operated mechanism. This was especially important to consider given the high operating temperatures of the cook stove and the desire to produce a device with an excellent lifespan.

2.7 Rationale for Choice

2.7.1 Design Process

Initially, Team Forge 2.0 team followed an individual approach to design. Individual members of Team Forge brainstormed and sketched ideas separately. Afterwards Team Forge 2.0 came up with about four sketches each, regrouped and explained each design in detail. This allowed Team Forge 2.0 to evaluate numerous innovative and creative ideas. The design team then proceeded by using a ranking system to determine which sketches were best overall with regards to cost, time of manufacturing and functionality of the design. The sketches and decision matrices used can be found in the Appendix. Finally, once the design team had narrowed the sketches down to the best two, Team Forge 2.0 chose what was believed to be the most feasible and least costly while still achieving the desired functionality of the stove.

The design team pivoted designs multiple times throughout this process based on testing results from the previous team’s stove as well as budget and timing constraints. Once Team Forge 2.0 began testing the previous team’s stove for particulate emission data, the design team was able to draw visual conclusions with regards to the degree of gasification throughout the burn. The first key observation made was that an increase in height of the combustion chamber dramatically increased the velocity of the air flow. This resulted from attempts to direct the stove’s exhaust towards a sensor by placing aluminum ducting on top of the combustion chamber. This led to the addition of a chimney, or windshield, to the stove which improved the air flow through the system, allowing for better performance.

The design team also determined that gasification became noticeably weaker as the fire dropped further below the secondary air flow inlets. This reduction in secondary ignition was characterized by a lack of flame coming out of the secondary inlets. In order to prolong gasification once the fire had dropped to a lower level, the design team determined it would be prefered to restrict the upper secondary inlets so no air would be lost through them and to add a second, lower row of secondary inlets to reunite the wood gas with air flow and thus continue the gasification process.

After brainstorming with the project advisor, Dr. Marks, Team Forge 2.0 determined the proposed lower secondary inlet row would need to be regulated along with the existing secondary inlets. A mechanism which operated automatically was initially preferred, in order to ensure consistent performance and increase usability, since less action from the user is required. Initially, it was thought that a mechanism which could turn based on the level of fuel in the combustion chamber would allow for the lower set of secondary inlets to open at the desired time during the burn. In order to do this effectively, the mechanism would have to sense temperature at the level of the secondary inlets. Gasification can be achieved only if temperature is high enough, at least 900°F for biomass.[12] An effective air flow regulating mechanism would sense when the temperature at the level of the upper secondary inlets dropped below this value and act to close these ports while opening the lower secondary inlets.

After researching technologies that could accomplish this behavior, such as bimetal actuators, it was determined that a mechanism which was operated manually would be more cost effective and less likely to malfunction, as long as the user had the proper instruction.

2.7.2 Risks and Mitigations

The biggest risk associated with the project is the dangerously high temperatures which the user is exposed to. These high temperatures encompass the entire stove and extend the length of the tall handles of the air flow regulator. The user must grip the handles tightly in order to

[12] Gasification vs. Pyrolysis.

move the mechanism from the open to closed position and back again. During testing, Team Forge 2.0 always wore thick leather gloves to handle the mechanism and stove in general. In an attempt to keep this design affordable to the targeted market of rural nicaragua, the design team determined ceramic insulation to be too expensive. The safety precaution must come from gloves and not from the stove itself. It is a risk the users of the stove may not heed to without specific warning and cautions will be made clear to the users in the safety manual viewable in the Appendix. A secondary risk is that the design will not be ready for implementation at the close of Senior Design. It is the design team's hope if this occurs, a team will choose to continue the cook stove project for their senior design the following year. Team Forge 2.0 has much insight into the stove and what refinements need to be made in order to have a user friendly product for developing countries.

2.8 Layout of System-Level Design

The main system is the entire cook stove. The cook stove includes the following subsystems: the cooking shell, the fuel, the air flow system, the air flow regulator, and the cooking surface. The cooking shell is comprised of annular canisters made of A1008 cold rolled steel. The inner chamber is where the fuel is burned and the outer chamber is where the unburned air travels upwards to enter the inner chamber to reignite the woodgas. The fuel is biomass which is collected and inserted by the user. The air flow system consists of the main inlets located on the outer chamber of the cooking shell, the primary inlets located at the bottom of the inner chamber, the lower secondary inlets located in the middle of the inner chamber, and the upper secondary inlets located at the top of the inner chamber. To elaborate on the difference between main and primary inlets, the term "main inlets" will be explicitly used to refer to the outer chamber inlets through which all air that enters the system passes. The term "primary inlets" will be explicitly used to refer to those located at the bottom of the inner chamber. The air flow system also includes the upper opening of the inner chamber through which the exhaust created by the stove is expelled, and finally the windshield which is placed on top of the cooking shell. The air flow regulator is made of mild steel and sits inside the combustion chamber, allowing air to pass through either set of secondary inlets. The last subsystem is the cooking surface, which is placed on top of the windshield and allows for heat transfer to pots, pans, or directly to food such as tortillas.

2.9 Team and Project Management

2.9.1 Project Challenges and Constraints

A total of $2,000.00 was requested from the School of Engineering at Santa Clara University. This was not a large amount of money as the design team wanted the stove to be as low cost as possible in order to meet a reasonable price point for targeted users. This budget constrained the design of the stove by limiting it to affordable materials. Copper was desired because it has a very high thermal conductivity and it was desired to distribute a large amount of heat to the cooking surface. This material was very expensive so A1008 cold rolled steel was chosen instead. This material is less expensive and has an adequate thermal conductivity of 65.2 W/mK that is sufficient for heat transfer from the fire to the pots and pans. Another desired material was ceramic since it is important to mitigate potential safety risks. The ceramic would insulate the combustion chamber of the cooking shell, however, this would increase the cost of the stove, making it less accessible to the targeted user. Additionally, tests conducted with a mild steel chimney made it apparent that mild steel was not the ideal material for the chimney. Its material properties made the chimney difficult to maintain as it needed to be ground clean before each use to prevent excess particulate release. Stainless steel was the more desirable material as it has preferable properties such as corrosion resistance. However, it is more expensive and would again make the product less affordable. Furthermore, since the typical user will not have a technical education, the cook stove not only needs to be affordable, but easy to use as well.

Regarding the results, the design team had hoped to quantify the amounts of particulate matter and various gases released such as carbon monoxide, carbon dioxide, nitrous oxides, and hydrocarbons. Due to the expensive nature of the optical measurement equipment capable of measuring these quantities, testing equipment was constrained to what was available through Santa Clara University. The team was able to quantify the particulate emission reduction from an open fire, this year’s design, last year's design, and a competing product. Due to budget constraints, further testing of the actual harmful gases rather than particulate counts weren’t conducted which may have led to more conclusive results.

There were many issues that arose during the testing of the performance of Team Forge 2.0’s cook stove relative to its competitors. The inaccessibility of proper indoor testing facilities forced all live-burn tests to be conducted outside, which led to loss of some environmental control. It was extremely difficult to manage changes in the environment’s wind speed and direction. A 10 foot tall windshield made of plywood was built to try to block the stove from the wind, as cooking indoors would. However, the wind was very strong some days and would still enter the cavity of the windshield where the stove was sitting. This could have caused a lot of variability when it came to the particle sensors being used to measure the amount of particulate matter produced from the stove. Ideally, there would be no wind during testing and the particulates released would travel upwards towards the sensors and an accurate reading would be obtained. However, the wind had the ability to blow some of the flow from the burn away from the sensors, making it extremely hard to regulate the experiment. In addition, the high operating temperature of the cook stove severely limited the range of options for testing materials and equipment, such as the thermal camera and thermometers used to obtain temperature distributions.

Although the prototype was manufactured in the Unites States, to produce an affordable product for developing countries, it is necessary to constrain the materials used to be readily available in Nicaragua. Utilizing manufacturers overseas will also be very helpful when trying to produce an affordable stove. These limitations mean that sourcing locally with help from Grupo Fenix is the next step in producing and implementing the Forge 2.0 cook stove.

2.9.2 Budget

The total budget that was requested was $2,000.00 for prototyping and $2,400 was requested for travel shown in Table 2.5. Due to the fact that last year’s design team’s original prototype was used, modified, and added to for this project, much less money was used than had been expected. The breakdown of these costs are shown in Table 2.6 below.

Table 2.5: Project funding.

Category	Source	Sought	Committed
Grant	School of Engineering	$2,000.00	$2,000.00
	Xilinx	$2,400.00	$2,400.00
Fundraising	N/A	N/A	N/A

Table 2.6: Cost estimates and actual expenditure.

Category	Estimated	Spent	Notes
Testing Materials	$420.00	$412.88	
Prototype	$810.00	$9.62	Lower cost curtesy of PWP manufacturing and Cleasby

2.9.3 Timeline

Last fall quarter, the design team solidified a design and chose appropriate materials. The team applied for the Roelandts Grant as well as to the School of Engineering and Xilinx for design funding based on a preliminary cost estimate and received a budget of $2,000.00.

During winter quarter, the team began testing the old stove to achieve quantifiable particulate data. This data was needed to determine if the proposed modifications would achieve a higher level of gasification that would result in a cleaner burn than the previous model.

This spring quarter, the old design was modified and physical testing and experiments began. With the help from the environmental studies and sciences department at Santa Clara Univeristy, testing was conducted using two TSI Condensation Particle Counters to quantify and compare the modified stove’s particulate elimination to last year’s stove, an open fire, and a competitor product. Moving forward, the design team is looking to reduce product costs by having the stoves manufactured in Nicaragua using locally sourced materials, and producing a large number of units.

2.9.4 Team Management

Throughout the year, the design team recognized each member's individual strengths and skills and applied those to different tasks to ensure that the goals of the project were reached. An incorporation of individual and team tasks to brainstorm, design, and produce a working cook stove resulted in the most efficient and enjoyable design process. Outreach, calculations, SolidWorks modeling, and researching were usually performed individually, while documentation, prototyping and testing were performed as a team.

Over the course of the past year Forge 2.0 has encountered challenges and setbacks that the design team has had to address and overcome. The design project is a collaborative process where the four team members had to work individually and together in order to ensure the completion of the project. At the beginning of the year when the team was first formed, it was decided that if conflict or challenges arose then team members will have to come to a unanimous consensus before moving on. Throughout the process the team had to contact and communicate with different organizations, advisors, and companies; it was important for Forge 2.0 to be prompt and organized so that the project could be completed to the best of Forge 2.0's abilities.

In the Fall, Forge 2.0 was focused on researching, strategizing, brainstorming, preliminary design. During this time, the design team decided to continue the Team Forge's thermoelectric cook stove and modify and refine the design. Based on the research conducted, information from Nicaraguan contacts, and Team Forge's results, the design team concluded to pivot; Team Forge 2.0 decided to change the scope of the project to design a clean burning cook stove that more effectively addressed the needs of the target customer. Grants and the necessary funding was acquired for the project during this time.

Winter quarter Team Forge 2.0 focused on testing and quantifying the emissions of the stove. Various tests were conducted and the results were analyzed in order to understand the stove's functionality. In the Winter a large percent of the time was spent trying to find out the most appropriate way to test the emissions of the prototype.Team Forge 2.0 attempted several testing configurations that led to inconclusive results and forced the design team to try different testing methods.

During the Spring Quarter Team Forge 2.0 was able to test the emissions of the prototype and determine the necessary modifications and alterations that could be made to maximize the stove's performance. Team Forge 2.0 focused its efforts on crafting and editing their thesis. Over the course of the year Team Forge 2.0 was able to use team management principles to complete the project to the best of their abilities.

Chapter 3 – Subsystem Chapter

The main system is the entire cook stove as a whole. This main system consists of the following subsystems: the cooking shell, the fuel, the air flow system, the air flow regulator, and the cooking surface. The role of each subsystem will be discussed in the following subchapters.

3.1 Cooking Shell

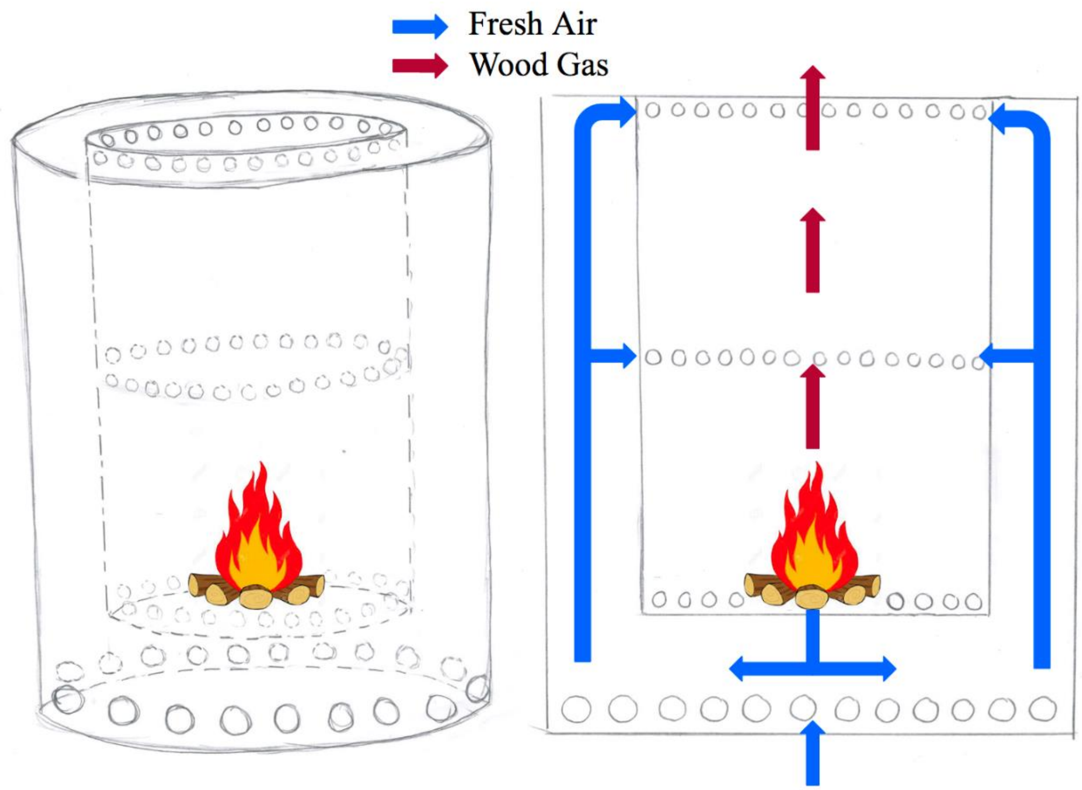

Figure 3.1: The Cooking Shell with air flow shown.

The cooking shell is comprised of two annular, cylindrical shells. The material had to be able to withstand temperatures as high as 1000°C without losing structural integrity. It was desired for the outer wall to be thermally insulating so the heat would be channelled upwards towards the pots and pans placed on the cooking surface and so minimal heat would be released to the environment. Thermal conductivity was also important for heat transfer from the fire to the unburned air in the outer chamber. Materials with high thermal conductivity, such as copper, would have been ideal for the cooking shell in this regard. However, this material has a melting point of 1085°C which is too close to the constraint stated above. The expensive nature of copper also made it unfeasible to use for the design of an affordable cook stove. A1008 cold-rolled steel was chosen as the material to be used for the cooking shell. This was due to the fact that this material had a low cost to weight ratio and also a sufficient thermal conductivity. Insulating material was not used on the outer shell in order to reduce material costs. Although it is extremely important to consider the user's safety when designing, current cooking methods expose users to high temperatures, so the tradeoff was made to save material costs and not insulate the outer chamber of the stove.

The inner shell encompasses the combustion chamber, which was made large enough to accommodate the natural fuel collected by the users. The diameter of the inner shell is 8 inches and has a wall thickness of 0.125 inches. Between the inner and outer shell is where the air flow system is located and where the unburned air flows upwards to enter the inner shell and reignites the wood-gas. The diameter of the outer shell is 12 inches and has a wall thickness of 0.125 inches. The height of the cooking shell is 18 inches.

Multiple different options and tradeoffs were considered when determining the dimensions of the stove. For example, the larger the stove was, the more cooking surface the users would have. However, a larger stove would require more material, making it heavier and more expensive. Another tradeoff dealing with the height of the stove was that if the chamber was shorter and wider, it could weigh less but still heat a large cooking surface. But, a shorter chamber would allow less time for cooking and gasification. This is because the entire larger surface of the fuel would be burning downwards at once, shortening the time of the burn.

Refueling during the cooking process is undesirable, as it may be difficult when the cooking surface is in place or there are pots and pans above the stove. The Solo Stove, that was referred to in the Benchmarking Results section, has a horse-shoe shaped lip around the top edge of its chamber with a gap to allow fuel to be inserted during a burn. This type of gap could also hinder the gasification process.

These tradeoffs led to the decision to alter the previous year's design to improve its performance rather than manufacture a new stove. Last year's design was proven to achieve gasification and allowed for a more cost-effective manufacturing process. A typical burn lasted about 50 minutes during testing of last year's prototype with these dimensions. This is a sufficient time for cooking the food that the users typically eat, i.e. tortillas, rice, and beans.[13]

[13] FORGE Thesis.

3.2 Fuel

The fuel used in the cook stove will be in the form of readily available biomass. Small sticks of a variety of woods will be collected around the users' community. These are about 1.5-2 inch in diameter and can be collected in bulk and placed into the cook stove for burning by the users.

3.3 Air Flow System

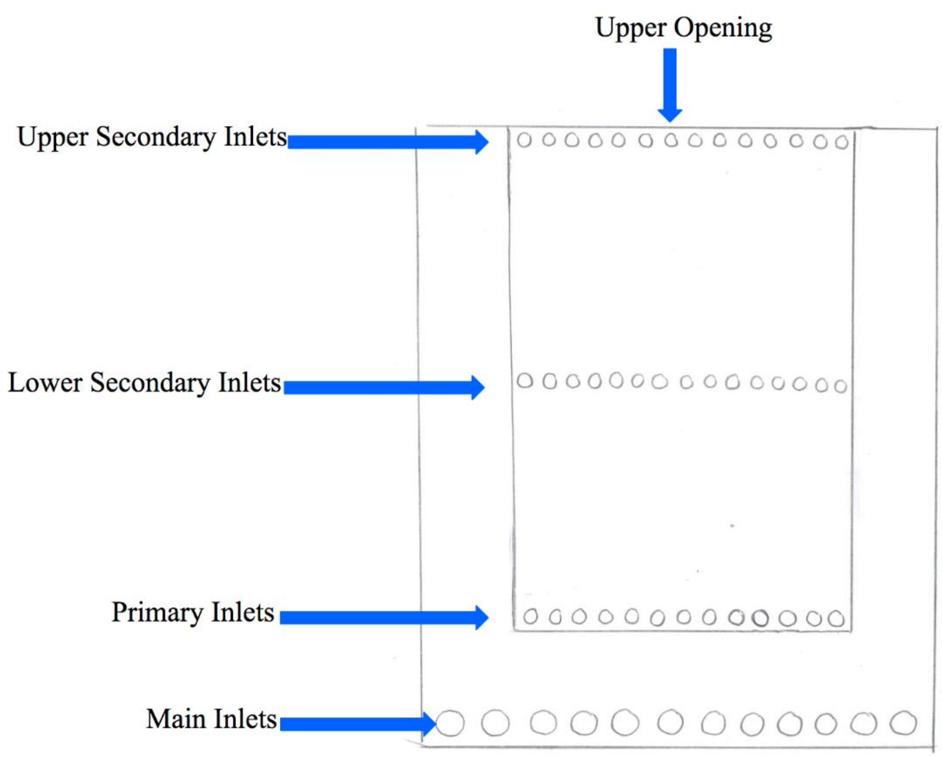

Figure 3.2: The air flow system.

The air flow system allows for the stove to utilize the gasification process, which will result in the reduction of harmful pollutants resulting from the combustion of the fuel. It also accelerates the air flow through the stove.

This subsystem is comprised of four sets of air inlets, the space between the inner and outer shells, and the stove's windshield. The main inlets are located at the bottom of the outer shell. These allow air to enter the stove's outer chamber. There are 19 main inlets of 0.75 inch diameter. From here, the air has two options. First, it can enter the inner chamber through the primary inlets, located at the bottom of the inner shell. There are 11 primary inlets of 1 inch diameter. This option allows for immediate combustion of the fuel which produces wood-gas. This wood-gas then flows upwards through the inner chamber. Second, the unreacted air can flow upwards through the space between the inner and outer shells until it reaches either the upper or lower secondary inlets, depending on the position of the air flow regulator. There are 20 upper secondary inlets and 20 lower secondary inlets of 0.25 inch diameter. The centers of the upper secondary inlets are located 0.56 inches below the top of the inner shell. The centers of the lower secondary inlets are located 5.31 inches below the top of the inner shell. When the air passes through these holes into the inner chamber, the wood-gas is reignited and secondary combustion takes place. This increases the heat output of the stove while also eliminating harmful emissions created from the primary combustion. Lastly, the air flows upwards through the chimney until it reaches the cooking surface. The windshield is an 8 inch tall cylinder with a 10 inch diameter and is made of mild steel. The cylinder is 0.25 inches thick. Its purpose is to shield the fire from the wind to enable consistent gasification and to accelerate the air flow.

There were a few tradeoffs considered during the design of the air flow system. All inlets were chosen to be circular because this shape is the easiest to manufacture and were spaced evenly along the circumference of both shells. If they weren't evenly-spaced, there could be pockets of wood-gas that wouldn't reignite, resulting in a less efficient gasification process. Different heights of windshields were used for a boiling water test and compared to each other. These were windshield heights of 18 inches, 8 inches, and no windshield. The windshield height of 8 inches provided the best performance.

The dimensions of the windshield chosen boiled water the fastest and is a standard part, which can be easily obtained. Further testing with different geometries of the inlets would have been ideal to ensure that the best design of the inlets were chosen. However, this would have required the construction of multiple prototypes, which did not fit our budget constraint.

3.4 Air Flow Regulator

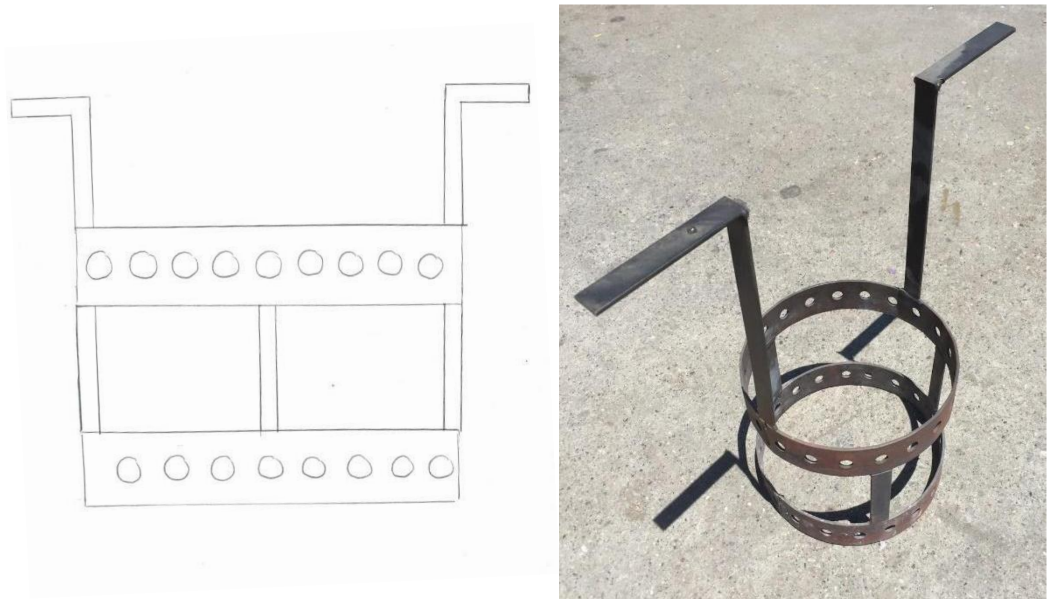

Figure 3.3: The air flow regulator.

Due to observations made during preliminary testing where the gasification process only lasted about 35 minutes into the burn, it was desired to have a mechanism that would allow the gasification to be prolonged. The purpose of the air flow regulator is to divert the air flow of the burn at the time when the gasification process begins to diminish. This mechanism can be positioned so that only the upper secondary inlets are opened while the lower secondary inlets are closed and vise versa. Prior to lighting the fuel, the user will position the air flow regulator so that only the upper secondary inlets are open. The user can then light the fire and observe the stove completely gasifying through all upper secondary inlets. After some time, the users will notice that not all upper secondary inlets are gasifying anymore. Once the user notices that only half of the upper secondary inlets are still gasifying, they can turn the air flow regulator, closing the upper secondary inlets and opening the lower secondary inlets. This will cause all the lower secondary inlets to begin the gasification process. This mechanism allows for the gasification process to last much longer.

The air flow regulator is made up of two concentric rings made of mild steel. This material was chosen because it also has a low cost to weight ratio and a sufficient thermal conductivity. They have an outer diameter of 7.75 inches and a height of 1 inch, and a thickness of 0.125 inches. They have holes measuring 0.44 inches in diameter that are offset from each other and are the same size as the upper and lower secondary inlets. They are connected by three supporting rods also made of mild steel. These rods are 0.75 inches in width and have a height of 3.75 inches. There are two 90-degree angle rods welded to the top ring to be used as handles. These rod are 0.75 inches wide, 8.25 inches tall, and the handles are 4 inches long.

3.5 Cooking Surface

The cooking surface is a rectangular slab of mild steel that is placed on top of the windshield. This material was again chosen for the same reasons stated above.

Chapter 4 – System Integration, Tests, and Results

4.1 Experimental Protocol

In preparation for our series of experiments we decided to first determine the ideal fuel size for our stove. We tested three sizes of fuel to determine which produced the cleanest burn. We determined the smallest fuel size yielded the least amount of visible emissions.

Due to the varying conditions of the fire, it was important to create as controlled an environment as possible. This meant creating a windshield and attempting to burn with as similar conditions as allowed. Before each burn we grinded the windshield to make it as clean as possible. We chopped our wood and packed the stove in the same way with a similar weight of fuel with tinder atop for easy ignition. Once burning, we kept a visual account of gasification by rating the number of secondary inlets gasifying at regular intervals, as well as noting the changes in smoke's appearance. Additionally we took a video recording of the burns for verification purposes alongside particulate sensor data and for determination of gasification duration, start and stop time as well as to verify the workings of the air flow regulator. In order to determine the amount of soil enhancement produced per initial biomass fuel we weighed the biochar at the end of each burn to compare to the initial fuel weight. A table organizing our experimental protocol can be seen in Table 4.1 below.

Table 4.1: Experimental protocol.

Evaluation	Quarter	Equipment	Accuracy	Trials	Expected Outcome	Formulae and Assumptions	Man Hours
Fuel Size	Winter	Stove, 3 fuel sizes, lighter, stop watch	Reduction of visible pollutants	6 total, 2 for each fuel size	Smaller fuel size will yield cleaner burn	Conditions are the same in each trial, size will affect burn time	6
Time to achieve/ cease gasification at upper secondary inlets	Spring	Stove, 1 fuel size, lighter, stop watch	60 seconds/15 minutes	6 with cleanest burning fuel size	<120 seconds/<18 seconds	Conditions are the same in each trial	6
Time to achieve/ cease gasification at lower secondary inlets	Spring	Stove, 1 fuel size, lighter, stop watch	30 seconds/10 minutes	6 with cleanest burning fuel size	<60 seconds/<13 min	Zero warm up time; conditions are the same in each trial	6
Reliability of slotted mechanism and timing	Spring	Stove, 1 fuel size, lighter, stop watch, air flow regulator	Achieve gasification at secondary inlet <30 sec upon being turned at visual sign of primary gasification reduction	6 with cleanest burning fuel size	<60 seconds	Conditions are the same in each trial	6
Environmental	Spring	Initial fuel weight, precise scale, extractor (rubber spatula), weighing pan	Zero waste, biochar measurement	3	<4 lbs	Conditions are the same in each trial	1.5
Pollutants eliminated/ remaining	Winter & Spring	Stove, 1 fuel size, TSI condensation particle counter	Greater amount of pollutants reduced from previous design and open fire	5, 1 w/o air flow regulator, 1 previous design configuration, 1 Solo Stove, 1 open fire	Pollutants significantly reduced with gasification	Conditions are the same in each trial	>10

In order to quantify the effectiveness of the cook stove as an emissions reducer relative to the previous team's design and to traditional cooking methods, the exhaust of the cook stove was analyzed using TSI Condensation Particle Counters. First, a wooden enclosure was created, with three sides being 4 ft wide and 8 ft in height. The fourth side was also 4 ft wide, but was only 5 ft tall and had a flat counter on which the sensors were placed. The stove was placed in the enclosure, 1 ft from the wall which the sensors were placed on top of. After the sensors performed a 10 minute warm up cycle, they were zeroed with provided filters which were placed over their intakes. The sensors then collected data for 10 minutes with the stove packed with fuel but unlit, to use as control. This was done before each burn configuration. The fuel was lit, and the sensors were turned on, taking particulate concentration readings every second for the duration of each burn. The sensors were turned off and the coals were extinguished when no visible flame was left in the combustion chamber.

4.2 Results

Live burns with Forge's original prototype allowed for the understanding of its performance as a cooking device and an emissions reducer. From these tests it was determined that the time for gasification to occur at all upper secondary inlets was approximately 10 minutes. These tests also led to observations which resulted in the addition of the windshield. The windshield accelerates the air flow through the stove and shields the secondary inlets from ambient air movement. With the addition of the windshield, the time for gasification to occur at all upper secondary inlets was reduced to 5 minutes. This meant that the fire achieved higher temperatures faster, and the stove was able to reach optimal performance as an emissions reducer more quickly than without the windshield.

Since the stove is intended to be a cooking device, boiling water tests were performed to compare Forge's design to Team Forge 2.0's design. Team Forge reported that their prototype brought 1kg of water to boil in 8 mins 45 sec.[14] Team Forge 2.0 performed a boiling water test by filling a 2qt pot with water (1.9kg). The pot was placed on the cooking surface when gasification was visible at all upper secondary inlets, and a timer was started. The timer was stopped when the water in the pot had come to a vigorous, rolling boil. This occurred 6 mins and 30 sec after the pot was placed on the stove. Thus it was determined that the modifications made to Forge's cook stove made the design a more effective cooking device.

Upon completion of the final iteration of Team Forge 2.0's prototype, several tests were performed to compare its performance to Team Forge's design, and to traditional cooking methods employed in Nicaragua. The initial test was performed without the air flow regulator,

[14] FORGE Thesis.

meaning both sets of secondary inlets were open during the entire burn. The TSI CPC 3007 particulate concentration data for this test is shown below in Figure 4.1.

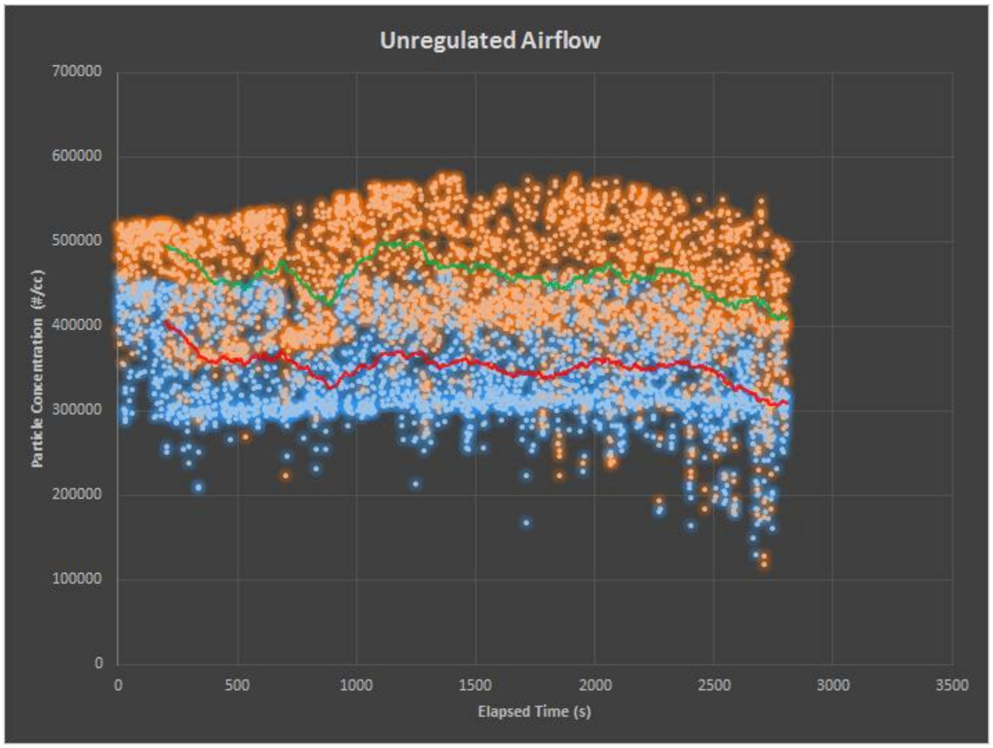

Figure 4.1: Plots a moving average of particle concentration for the unregulated air flow configuration.

Two particle counters were used during these tests, shown by the orange and blue data points, respectively. The green and red lines represent a moving average of the data. The readings from the two sensors varied dramatically, but the data trend throughout the burn process was similar for both sensors, thus it was determined that while the actual number of measured particles may not have been accurate due to calibration error, the sensors were behaving in the same way and were reliable instruments. The purpose of these tests was to compare performance for various burn conditions, so as long as the sensors were behaving in the same way, reliable conclusions could be drawn from one test's data relative to another. This was ensured by collecting data from the ambient air before the burns were initiated for every test, to use as control. The total average particle concentration for the unregulated air flow configuration represented by Figure 4.1 was found to be 405,000 particles per cubic centimeter. Figure 4.2 below shows the results of the next test, which was performed with the air flow regulator and its intended action.

Figure 4.2: Plots a moving average of particle concentration for the regulated air flow configuration.

The moving averages for each sensor are once again represented by the green and red lines, and the total average for this configuration was found to be 354,000 particles per cubic centimeter. During this test, the air flow regulator was turned manually 1700s into the burn, when the level of burning fuel reached the height of the lower secondary inlets. Upon turning the air flow regulator, the upper secondary inlets were closed, and the lower ones were opened, allowing gasification to occur at those ports. Since the average particle concentration for this configuration was lower than the unregulated air flow configuration, it was concluded that the air flow regulator was effective in increasing the duration of gasification for Team Forge 2.0's prototype. With this knowledge, it was necessary to compare the regulated air flow configuration to the performance of Team Forge's design.

The equipment required for these tests were obtained after physical modifications had already been made to Team Forge's cook stove, so it was necessary to approximate the performance of their design with materials available to Team Forge 2.0. The air flow regulator was left in place and unturned, so that the upper secondary inlets were open during the entire burn. It is also necessary to note that the windshield, not included in Forge's design, was used during this test in order to direct the exhaust consistently towards the particle counters. The results of this test are shown below in Figure 4.3.

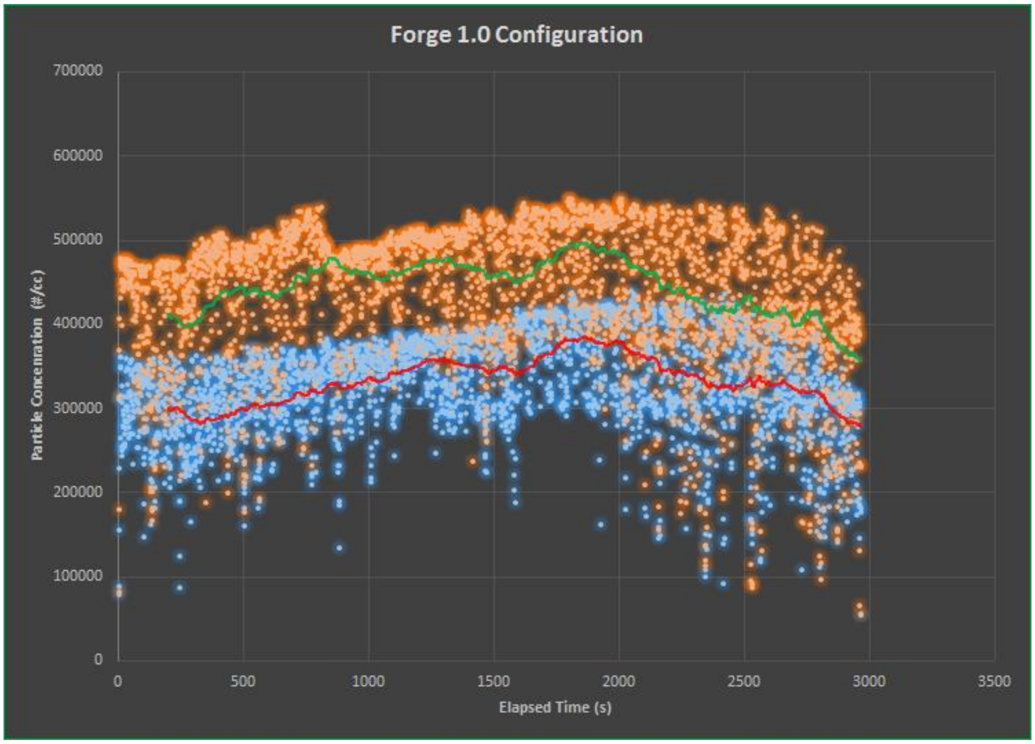

Figure 4.3: Plots a moving average of particle concentration for the approximated Forge configuration.

The moving averages for each sensor are once again represented by the green and red lines in Figure 4.3. The total average for this configuration was found to be 385,000 particles per cubic centimeter. This average is an increase of 8% compared to the average determined for the regulated air flow configuration shown in Figure 4.2, which is the intended use for the Team Forge 2.0 prototype. Thus it was determined that the modifications made by this design team made the cook stove a more effective emissions reducer. The Solo Stove Lite, a competitive product designed for backpackers that utilizes gasification of biomass (shown below in Figure

4.5) was also tested in the same manner.

Figure 4.4: The Solo Stove Lite.

The data obtained from testing the Solo Stove Lite is shown below in Figure 4.5.

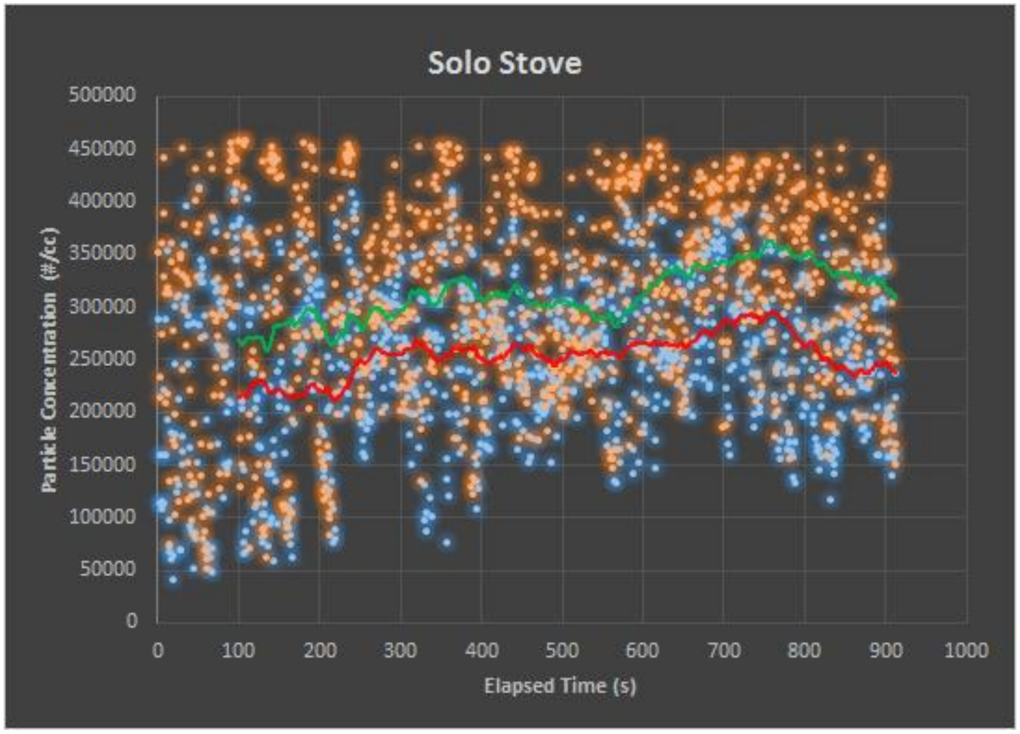

Figure 4.5: Plots a moving average of particle concentration for the Solo Stove Lite.

The total average for particle concentration released by the Solo Stove Lite was found to be 279,000 particles per cubic centimeter. As shown by the graph in Figure 4.5, the data collected by the particle counters was very sporadic. Due to the small size of the Solo Stove Lite, the amount of exhaust it produced was much less than the amount created by the Forge cook stove. The smaller amount of exhaust was affected much more by movement in the ambient air, which is revealed by the large number of data points at relatively low particle concentrations. The sensors were not able to take in the exhaust constantly, which led to the conclusion that this test was ineffective for comparing the performance of Team Forge 2.0's cook stove relative to this competitor.

The final configuration tested using the particle counters represented the traditional cooking methods currently used in rural Nicaragua. The windshield, which is a 10in diameter pipe of mild steel, 8in in height, was placed on top of two bricks to allow air flow from the bottom. The pipe was then packed with fuel as in the previous tests and lit. The results from this test are shown below in Figure 4.6.

Figure 4.6: Plots a moving average of particle concentration for an open fire configuration.

Consistent with the previous tests, the green and red lines represent moving averages for each sensor. As shown in Figure 4.6, there is much less fluctuation in the sensor data for this configuration. The fluctuation in the data collected in the tests with the stove, which achieved gasification, demonstrates that the gasification process does affect the amount of particulate matter released by the fire. The total average for the open fire configuration was found to be 480,000 particles per cubic centimeter, therefore it was concluded that the Forge cook stove is effective at reducing emissions if replacing traditional cooking methods. The results of these tests are tabulated below in Figure 4.7.

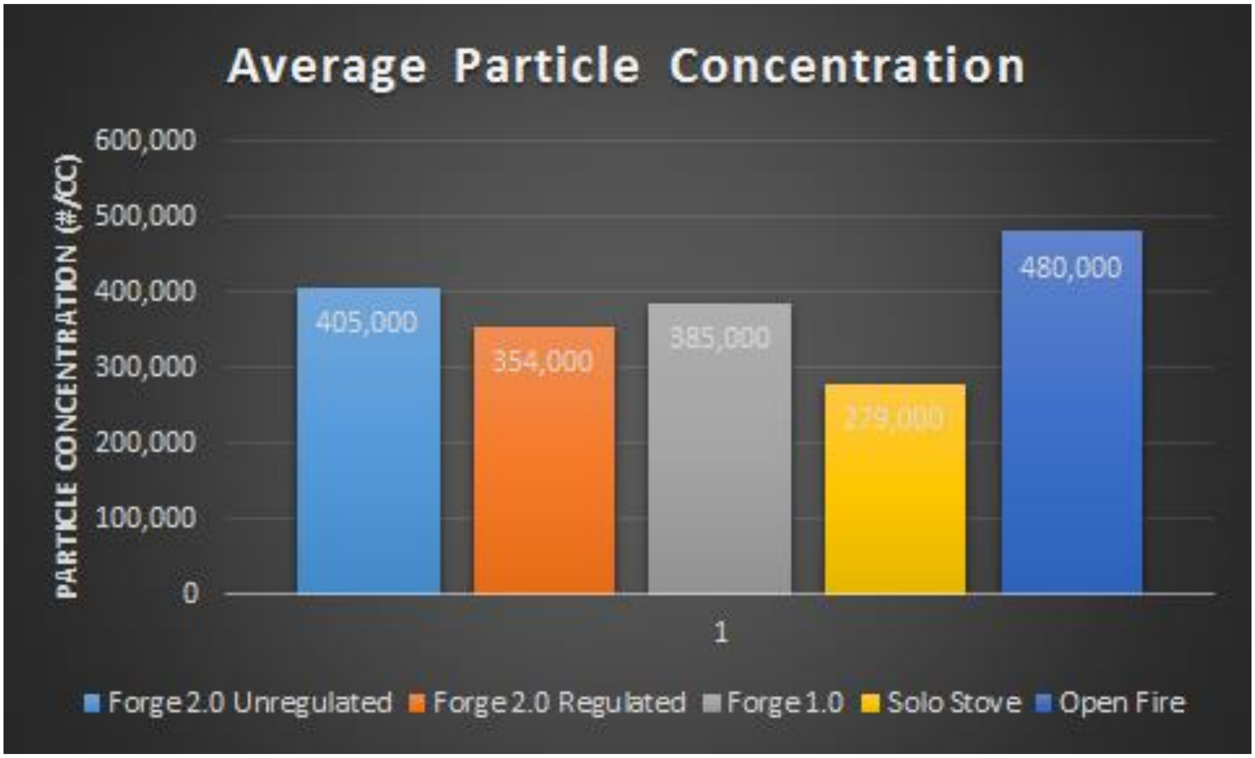

Figure 4.7: Organizes the data collected using the TSI Condensation Particle Counters.

It is important to note that the specification sheets provided with the TSI Condensation Particle Counters stated their accuracy was ± 20%, which made it difficult to be confident that the data collected were representative of the true values for particle concentration. Given the purpose of the tests were to compare performance of the Forge 2.0 stove relative to its competitors, as long as the sensors were behaving in the same way for each test that was run, this was possible. However, the reliability of the data may have been affected due to the operating ranges of the sensors. The specification sheet stated the concentration range was between 0 and 100,000 particles/cm^3. Limitations of the sensors may have been observed during the open fire test, shown in Figure 4.6, where it seems that the signal from the sensors were saturated due to the approaching of an upper limit. Since each burn lasted approximately 50 minutes, it was possible that the ambient environmental particle concentration would change and affect the results. To provide an opportunity to account for this change, as well as in order to validate that the sensors were performing in the same manner for each test, control data was taken, the results of which are shown below in Table 4.2.

Table 4.2: Statistical data from TSI sensors.

Day	Burn Configuration	Experimental Data				Control Data			
		Mean Particle Concentration	Standard Deviation			Mean Particle Concentration	Standard Deviation		
		(particles/cm^3)	Sensor A	Sensor B	Mean	(particles/cm^3)	Sensor A	Sensor B	Mean
Day 1	Forge 2.0 Unregulated	405000	57264.44	67887.44	62575.94	36715	4555	4499	4527
	Forge 2.0 Regulated	354000	58421.90	92707.85	75564.88	43367	1378	1384	1381
	Forge 1.0	385000	87081.70	79699.76	83390.73	38377	1899	1845	1872
Day 2	Solo Stove	279000	77850.80	94013.53	85932.16	23794	2484	2384	434
	Open Fire	480000	40604.31	19423.30	30013.80	23719	721	495	608

Given that the highest value for ambient particle concentration was observed before the Forge 2.0 Regulated test was performed, it can be claimed that the particulate reduction may have been more than the aforementioned 8% relative to the previous year's design. However, the differences in ambient particle concentration for day 1 were all within 20% of the smallest value obtained, which was 36715 particles/cm^3 for the unregulated air flow configuration. This meant that the averaged values were within the stated accuracy of the instruments, and it was assumed the sensors were behaving similarly, and the control values were similar enough that the experimental data did not need to be altered to reflect the differences in ambient particle concentration.

4.2.1 Comparisons to Predictions Based on Initial Criteria

Compared to what our design team initially set out to accomplish, our results fulfill 7 of our 8 initial criteria. We have achieved the gasification process and reduced particulate emissions from the previous design. Additionally, upon mass manufacturing, distribution and an appropriate business plan, our stove will fall within a reasonable price range for our targeted users. Our stove will run on locally sourced fuel and use the less than traditional cook stoves.

The gasification process allows for the recombustion of the products of the initial combustion, which increases the efficiency relative to traditional wood-fire stoves. This means less fuel is needed for a given heat output. Finally we have a user manual in Spanish for our Nicaraguan users to ensure there is nothing lost in translation regarding the operations or safety of our stove.

Table 4.3: Comparison of the final cook stove's performance to initial criteria.

Initial Criteria		Results
Clean burning	Gasification process	✔
	Reduce particulate matter from previous designs	✔
Affordable	Within reasonable price range	✔
	Approximately $100	
Highly efficient	Cooking performance (boiling water)	✔
	Less fuel used	✔
Safe and easy to use	Straight-forward user manual	✔
	Locally sourced fuel	✔

4.2.2 Comparisons to Traditional Methods, Past Projects and Competitors

After gathering and analyzing our particulate sensor data we were able to compare the results of our stove both with and without the air flow regulator to last years design, one of our competitor's designs as well as an open fire. The results showed a significant reduction of about 8% when burning in our regulated design when compared to last year's design. The traditional open fire proved to be the dirtiest burn as expected followed by our unregulated stove design, last year's design, our regulated design and our competitor the Solo Stove, respectively. We believe due to the small size of the Solo Stove it does not compete directly with our product. These results can be seen tabulated below.

Table 4.4: Comparison of final cook stove's performance to past projects, competitors, and traditional methods.

Competitor	Average Particulate Emission (particles/cm^3)	Fuel	Cost
Team Forge 2.0 Unregulated	405,000	Biomass	$700.00
Team Forge 2.0 Regulated	354,000	Biomass	$800.00
Team Forge	385,000	Biomass	$847.37
SoloStove	279,000	Biomass	$70.00
Traditional Open Fire	480,000	Wood	$0.00

Chapter 5 – Business Plan

5.1 Executive Summary

Team Forge 2.0's design utilizes the process of gasification to burn off harmful byproducts released from the combustion of biomass. In rural areas in developing countries many families still cook indoors using traditional cooking methods and this has resulted in high rates of respiratory diseases and premature deaths. Team Forge 2.0's target community for its stove is rural Nicaragua. Based on manufacturing costs, competitors' prices, and our target customer's income, Team Forge 2.0 set a target price for $100. The business plan comprises of several stages of implementation. First, is a trail phase where a controlled number of stoves will be shipped from the United States to Nicaragua and sold in partnership with Non-Governmental Organizations located in rural Nicaraguan, like Grupo Fenix. After this stage, the value, functionality, and practicality of the stove will be evaluated; based these results, the stove will either be scaled up to mass production or will pivot to a gasification stove kit.

5.2 Introduction

In Nicaragua it is still common practice to cook indoors over wood fires; this traditional practice exposes users to toxic exhaust that contributes to respiratory disease. According to the World Health Organization, respiratory ailments are most common in women and young children who “spend the most time near to the domestic hearth.” Smoke-induced pneumonia, bronchitis, asthma, lung cancer, and other respiratory diseases cause an estimated 4.3 million deaths worldwide annually.[15] The Forge 2.0 Stove aims to reduce this number by offering an alternative cooking device that is clean burning, affordable, safe, durable, and efficient. The Forge 2.0 stove is a cylindrical cooking device that creates a clean burn and high temperatures by using the gasification process. The unique geometry and air flow system of our stove allows for the gasification process to occur. Respiratory illness caused from traditional cooking methods is a global issue, and Team Forge 2.0 attempts to address this issue, specifically in rural Nicaragua, where a majority of people still cook with unsafe methods. The Forge 2.0 stove offers value to the community because it provides an efficient cooking device that is healthier and safer to use than traditional methods while still allowing traditional cooking styles.

Nicaragua is the poorest country in Central America, where 75.8% of the population lives on less than $2 per day.[16] A loan system will have to be implemented where users can pay for the stove in installments so that it can actually be put to use.

There are several other clean burning cooking stoves that use gasification, but are not specifically designed for developing nations. Competitors are designed for outdoor camping and heating purposes.

[15] World Health Organization.
[16] Unidos.

5.3 Goals and Objectives

The goal of Team Forge 2.0 is to successfully implement the cook stove into rural Nicaragua and generate a profit. Team Forge 2.0 is not solely profit driven; Team Forge 2.0's business approach is to focus on the triple bottom line. The triple bottom line is a term for entrepreneurial ventures that strive to create measurable social and financial results. This principle focuses on three key elements: social, environmental, and financial; these elements will help Team Forge 2.0 evaluate their performance in a broader perspective to create greater business value. Forge 2.0 will be a social enterprise that generates monetary profit while still creating measurable social benefits and improvement of sustainable environmental processes. Implementation of Team Forge 2.0's stove into the market will allow for customer feedback and tracking growth. It is important for Team Forge 2.0 to gauge the usability and functionality of the stove once it is integrated into the community because revisions and design changes may be necessary once implemented. Team Forge 2.0 plans to meet the needs and expectations of both customers and investors.

Team Forge 2.0 is a social enterprise that uses commercial strategies to maximize human and environmental well being. It is Team Forge 2.0's mission to provide a clean burning stove that will benefit the community by replacing traditional stoves; therefore, reducing the amount of exhaust inhaled by users while still generating a small profit. The profits realized by the stove will be reinvested in the business, and then put towards expanding Team Forge 2.0's reach and improving the stove itself. Team Forge 2.0's business plan is self-sustainable model that is not dependent on donations or on private or public grants to operate. Unlike nonprofits that spend funds only once in the field, Forge 2.0 will be invested into the business to increase and improve operations in the field.

In order to successfully implement the cook stove, Team Forge 2.0 will coordinate with partners to help facilitate distribution of the product, meet customer needs, and reach long-term penetration. In order to maintain low cost and reach the customers at the end of the supply chain, Team Forge 2.0 will work with non-governmental organization (NGOs). Forge 2.0 has been in contact with two NGOs located in Northern Nicaragua that have knowledge of the market and a customer base. Proleña works to build and distribute cook stoves and plays a pivotal role in ensuring that Forge 2.0's stove reaches the customer and achieves the desired social impact.

Grupo Fenix has provided Team Forge 2.0 with extensive knowledge of customer needs and possibilities for implementation and local production of the stove.

Finally, Team Forge 2.0 plans on executing a three-phase business plan that will introduce the stove into the market, refine its performance, and eventually scale up to mass production. The initial trial phase of the business plan is to partner with Proleña or another NGO that will facilitate the delivery of prototypes to customers in rural villages. In the second phase, Team Forge 2.0 will reevaluate the strategy and make the decision whether to begin manufacturing in Nicaragua, if any design features need alteration, or to switch to a gasification cook stove kit. In the third and final phase, Team Forge 2.0 plans to scale up to reach a larger market base.

5.4 Description of the Product

Team Forge 2.0's product is a cook stove that harnesses the gasification process to reduce the amount of exhaust released while working as a functional cooking device. Team Forge 2.0's stove has a novel design that allows for the optimization of the gasification process. The stove is composed of several subsystems. The cooking shell is comprised of two annular cylindrical shells made of A 1008 cold rolled steel. The inner shell is the combustion chamber which houses the fuel collected by the users. The outer shell surrounds the inner shell and houses the air flow system. The air flow system draws in fresh air for combustion and also transports the unburned air to the inner shell where it combines with the wood gas and reignites. The air flow system allows for the gasification process to occur; the high temperatures that the stove achieves allows for the fire to have a more complete combustion therefore reducing the amount of harmful exhaust. The air flow system is comprised of several sets of air inlet holes that allow for air to travel throughout the stove and optimize gasification. The main inlets, located at the bottom of the outer shell, allow air to enter the outer chamber. Once in the outer chamber the air either enters the inner chamber through the lower inlet holes located on the inner shell or flow upwards through the space between the inner and outer shells and reignite through the secondary inlet holes. There are two sets of secondary inlet holes located on the inner shell; there is an upper and lower set located at the top of the stove and then one on the bottom. These two sets of secondary holes can be opened and closed by using the air flow regulator. The air flow regulator is two concentric rings of holes that can open and close the secondary holes to optimize and prolong gasification. The wind shield is a cylindrical chimney that protects the upper secondary inlet holes accelerating the start of gasification. Finally the cooking surface is a rectangular slab of mild steel that is placed on top of the windshield that functions as the stove top.

Team Forge 2.0's stove creates value because it offers an alternative safer, healthier, and more efficient device to the traditional wood burning stoves on the market. The Forge 2.0 stove is unlike other products in the market and address the problem of respiratory disease. Other stoves on the market also use the gasification process to create a cleaner burn, but are expensive and not focused towards use in developing nations.

5.5 Potential Markets

As previously stated Team Forge 2.0's target market is the Northern rural communities in Nicaragua. This is a small impoverished community located in the mountains of Nicaragua. Team Forge 2.0 decided to focus on this community because it does not have access to proper healthcare, electricity, plumbing and other resources. Also Team Forge 2.0's contacts in Nicaragua were able to provide useful customer information that helped Team Forge 2.0 design the stove to meet their needs specifically. By working with Nicaraguan contacts Team Forge 2.0 has been able to identify a problem and develop a solution based off of the market's specific needs. Currently Team Forge 2.0's target market is rural Nicaragua, but this could be scaled up to include other rural communities if the stove's implementation is successful.

One of the biggest challenges with the rural Nicaraguan market is its isolated location. According to the design team's contacts, developing a supply chain would be the most challenging part is developing a supply chain. Grupo Fenix and Proleña both suggested addressing this by building the stove on location. Proleña also builds cook stoves for the market but do not gasify; the Forge 2.0 stove has a competitive advantage because it burns cleaner. Currently, Nicaraguans either use traditional open fires or a non-gasifying cooking device; the Forge 2.0's stove offers a safer alternative to the current stoves on the market. Proleña distributes several different models of stoves that also reduce the amount of fuel required and have chimneys that transport the exhaust.

Team Forge 2.0 believes that the rural Nicaragua is an appropriate environment to test the scalability and use of clean burning cook stoves in the field. Grupo Fenix and Proleña both provide a channel to connect to potential customers in our target market. If Team Forge 2.0's target price of $100 is not possible, then a different strategy must be attempted; Team Forge 2.0 could use a similar strategy to Proleña or work with Proleña to manufacture on site therefore reducing the cost. Compared to the other stoves that Proleña produces, the Forge 2.0 stove creates a cleaner burn, is more cost efficient, and more mobile. If implementation is successful, then manufacturing would be increased to a larger scale and necessary modifications to the prototype can be made. Integration of the Forge 2.0 stove into this community can lead to expansion of distribution into other communities.

5.6 Competition

Proleña is the largest source of competition for Team Forge 2.0, however, for the same reasons as Proleña is a competitor Proleña would be an excellent business partner. Since Proleña is already an established distributor within Nicaragua, Team Forge 2.0 plans to partner with them to ensure the Forge 2.0 stove reaches its intended user and brings about the desired social impact. Proleña builds stoves on location, however, they do not gasify, giving the Forge 2.0 stove a competitive advantage over other stoves Proleña distributes. Other than Proleña, most competitors are small scale clean burning stoves designed for camping or providing warmth. These camping stoves are fueled by local biomass, the same as the Forge 2.0 stove. For example, the BioLite and Solo Stove which showcase the portability of their product as well as some electrical components.

The BioLite stove uses a USB rechargable air flow system that requires the user to first fully charge this small scale stove before it can effectively reduce emissions. Measuring 7.91 inches high by 5 inches wide, this product is impractical for the targeted market of Nicaragua. Since families tend to cook together in large quantities as well as the charging element limits the hours of operation since the community of Totogalpa uses solar energy during the day but do not have access at night. Additionally, this product is marketed towards campers who prefer not to burn or carry a gas canister, not towards developing countries.

The Solo Stove Lite, Titan, Campfire, Bonfire models range in size from serving 1 to 4+ people. The smaller models would be impractical for the targeted market of Nicaragua due to family style cooking and portions, however, the larger styles that serve 4+ people are more direct competitors to the Forge 2.0 cook stove. The Campfire model claims to cook for 4+ people, however, the stove measured only 9.25 inches high and 7 inches wide. It is marketed towards the popular family camping tradition of toasting marshmallows instead of cooking beans and tortillas as the Nicaraguans intend. The Bonfire model is the largest stove, measuring 14 inches tall and 19.5 inches wide, that Solo Stove produces and is marketed towards backyard bonfire seekers who primarily want the warmth a fire provides. Additionally, this larger model designed to provide heat is a more practical size, however, requires full logs to burn. This product is "not designed with cooking as the main objective"[17] and again, not marketed toward developing countries.

The Forge 2.0 stove is designed for cooking the developing country market unlike Solo Stove products and can be fueled with local biomass. Additionally, the Forge 2.0 stove does not rely on electricity to reduce harmful emissions like the BioLite. Although technologically effective for their targeted uses, these products from BioLite and Solo Stove are not ideal for large family style cooking in developing countries.

5.7 Sales and Marketing Strategies

In order to properly market and sell the Forge 2.0 stove, it is important to prove to our target customers the value and practicality of the stove. Working with contacts and on site implementation Team Forge 2.0 will advertise its stove to the local community. It is critical that Forge 2.0 draws attention to its stove through a public medium in order to promote sales. Team Forge 2.0 plans to do this by working with Grupo Fenix and Proleña to inform isolated Nicaraguan communities about the product. With their help Team Forge 2.0 can advocate the potential benefits of the stove and create a relationship with our customer base.

As stated earlier, the target customer lives well below the poverty line and does not have large amounts of disposable income to purchase the Forge 2.0 stove in one payment. Team Forge 2.0 will use methods similar to Proleña that will allow customers to pay for the stove in

[17] Solo Stove Bonfire FAQ's

installments, as a collective or by using their own labor to build stoves on site.[18] According to Grupo Fenix, many of the locals live and cook together in familial groups, so it is possible for families to pool funds collectively to pay for the stove. Currently Nicaragua has a multi million dollar microfinance market that give out loans to families and small businesses.[19] By using this existing network Team Forge 2.0 will be able to allow for customers to take out small loans to pay for the stove over time rather than one lump payment.

Team Forge 2.0 plans to reach last mile customers who are outside the reach of traditional supply chains. In order to make measurable social change for those who need it most Team Forge 2.0 must reach these customers.

5.8 Manufacturing Plans

Initially, the Forge 2.0 stove will be manufactured here in California and shipped to Nicaragua. PWP Manufacturing or Cleasby Manufacturing can provide machining and assembling services. Upon given an order, which would be for 10 units initially, Cleasby Manufacturing could complete this order in less than one week. PWP Manufacturing could complete the order on a similar timeline, and may be a better option given their proximity to Santa Clara University. The initial units would need to be inspected and tested before sending them to Nicaragua. Materials and manufacturing costs would be on the order of $500 per unit if this route is taken, meaning Team Forge 2.0 would need $5,000 to build an initial inventory. These costs would be reduced as more units are made, and according to PWP Manufacturing, the price per unit to produce could be reduced by as much as 30% given a large order. In order to reach the target price of $100 per unit, this cost would need to be further reduced.

An option for reducing the cost per unit dramatically would be to locally source materials and manufacturing processes. One way to do this would be to teach locals to complete a gasification stove kit, based on the design of the stove created by Team Forge 2.0. Using standard parts, such as steel pipe, air inlets could be hand drilled, and local manufacturers could

[18] Proleña.
[19] Central America Data.

weld the seams to create a product which achieves the same gasification effect as the Forge 2.0 stove. This would also eliminate shipping costs, however it is unknown how much material would be present and at what rate the stoves could be produced.

Additionally, locally sourcing the manufacturing would create a loss of quality control and assurance. It is imperative the seams be airtight for the stove to function properly, and welding sheet metal often poses difficulties. The professionals at PWP and Cleasby Manufacturing would allow for confidence in the quality and performance of the stove, and would be preferable for the initial stages of production, when the stove is first being introduced into Nicaragua. With an initial inventory in place which has been proven to perform as expected, it would be easier for local manufacturers to copy the design and reduce the cost of production, eliminate overseas shipping, and moving the retail price of the stove towards the target of $100. This would then allow for more units to be produced given material availability in Nicaragua.

5.9 Product Cost and Price

The target price for the Forge 2.0 stove is $100 in order for it to be affordable for rural residents of Nicaragua, the poorest nation in Central America. Initially, the Forge 2.0 prototype, manufactured by PWP Manufacturing, cost $700. According to that manufacturer, when scaling up production volume, which would reduce material costs, there could be as much as a 30% reduction. Labor is the most expensive portion of this cost. Since labor is a fixed cost, it would be desirable to find a different manufacturer that would initially charge less. Cleasby Manufacturing could provide the same service at a lower labor cost of $30/hr, and could still produce a large number of units while allowing for reduced material costs due to bulk ordering. Given a large order of units, contracting with Cleasby Manufacturing could bring the cost per unit down to $150 assuming 4 hours of labor and $20 in material cost for each unit.[20] In order for the Forge 2.0 stove to turn a profit, this would mean the retail cost would be well out of the price range for the target market.

Competing products such as the Solo Stove Campfire and the BioLite stove sport similar

[20] FORGE Thesis.

retail prices, at $150 and $130, respectively. In order for the Forge 2.0 stove to compete with these products a price reduction through cheaper manufacturing methods would be needed, given assurance that the quality would not be lost. Processes such as powder metallurgy or casting would be viable options, despite their high fixed costs.[21] These high fixed costs are solely required at the outset of the manufacturing process, however. The high costs of molds would eventually be offset by the savings made by producing a higher volume of units.

5.10 Service and Warranties

The Forge 2.0 cook stove is expected to have a lifespan of about five to ten years. The materials used to manufacture the stove will undergo cyclic loading due to the fact that families will be using the stove to cook their meals at least once a day. Cyclic loading will cause the stove to experience fatigue degradation with continued usage. However, embrittlement of the stove was not something to worry about because the type of steel used has material properties that would not be affected by the high temperatures the stove will be experiencing. The stove was designed to be extremely durable and it is improbable that something would happen that would cause the stove to need repairs, i.e. the stove won't somehow obtain a hole that needs patching. Therefore, no repair services will be provided once the stove is purchased.

Because the materials chosen for the stove are extremely durable, it is very unlikely that the stove would become defective earlier than towards the end of its expected lifetime. Once the stove does become defective, the best thing for the users to do is invest in a new stove. However, if the stove somehow does fail much earlier in its usage than expected, it is Team Forge's duty to provide the users with a new stove. Therefore, the stove will have a warranty of three years. If the stove stops working within three years of purchase, the stove will be completely replaced at no extra charge to the customer and its parts will be recycled and used to manufacture more stoves.

5.11 Financial Plan

[21] FORGE Thesis.

In order to fund this project Forge 2.0 plans on acquiring resources through angel investments and through student focused social entrepreneurial grants. Team Forge 2.0 is a social venture that plans to generate profits while creating measurable social change. In order to do this the proper funding is necessary. By presenting the Forge 2.0 cook stove to investors and

To produce an initial inventory of 10 units, which would be inspected and tested for quality control, Team Forge 2.0 would need a donation of angel investment of $4,000. This would cover the cost of manufacturing which can be expected to be $2,000 for this volume by Cleasby Manufacturing. This would allow $2,000 for overhead costs and shipping. When these units are implemented, it is possible that certain observations would lead to design changes. These changes could then be made and upon assessment of the effectiveness of the stove and therefore the demand for it, production volumes could increase. At this point, Team Forge 2.0 would be $3,000 in debt, and would need an additional grant of $15,000 to contract with Cleasby Manufacturing for the production of 100 units. Another $3,000 would be needed for shipping costs, which would amount to $1,000, leaving $2,000 for overhead costs.[22] This second stage would still leave Team Forge 2.0 $11,000 in debt.

Knowing this, it is important that past this second stage, in order to turn a profit, manufacturing costs must be lowered by locally sourcing materials and labor, or implementing alternative manufacturing methods. With enough successful units in place in Nicaragua, technicians could be trained to manufacture the parts needed from locally sourced materials, or use standard parts which are readily available to make a product with similar performance to the Forge 2.0 stove.

Chapter 6 – Engineering Standards and Realistic Constraints

6.1 Economic Impacts

Our design team asked PWP Manufacturing, LLC, the company that manufactured last

[22] ShippingQuest.

year's stove, how much it would cost to mass-produce these stoves. Tom Martino, general manager, told us that last year's stove should have cost $1400 to produce since it was only one unit and if the stove were mass-produced, they would cost $250-$300 each since "there is a lot of manual labor required to roll the rings and weld all the seams". Ideally the final design of our stove would be mass produced and implemented into the 500-600 homes that use inefficient and unsafe indoor cooking stove in Nicaragua, however, the estimated price of $250-$300 for a mass produced product is still too high for our customer.

Because these families live in rural Nicaragua, it is highly unlikely that they will be able to afford these stoves without some sort of help. On top of this, mass-production of these stoves would be very costly up-front as well as transportation of the stoves to the area of need. We would have to take out some loans to be able to produce enough stoves for the communities of Nicaragua, resulting in a higher cost per stove. This inflated price is a clear indicator that we must find a more economical way to produce these stoves so that rural families in Nicaragua can afford them. A possible solution to this problem would be to find a manufacturer who would provide their services more cheaply than PWP Manufacturing. One such company is Cleasby Manufacturing, which would be able to produce a large number of stoves at a price of $150 per unit. Shipping an inventory of 100 stoves to Nicaragua would cost $1,000, so a sizable loan would still be necessary for this second stage of production, around $18,000.[23]

We looked into potential ways to reduce the cost and one solution we found is off-shoring manufacturing. Martino stated that this would reduce the cost by 50-60%. If it was possible to manufacture the stove in Nicaragua, costs of transportation and material would also decrease. Martino also told us another way to decrease the stove's cost would be to use robotics rather than manual labor, which he believed would decrease the cost of the stove by another 20%.

42.5% of Nicaraguans live below the poverty line, living on less than $1 USD per day.[24] Since our target market does not have much disposable income we had to create a system that would allow users to pay for a stove in installments. By allowing our customers to pay for the stove in installments after a down payment, our customers are able to use the stove and pay with

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[23] ShippingQuest.
[24] Unidos.

little interest. This means that the profit margins on our stove will not be very high or immediate; if this plan is successful our team should eventually make back the money invested in the production and design of the cook stove with a small profit margin. The purpose of this social enterprise is to improve the quality of life for those in Nicaragua while also generating a profit. The main objective though is not profit driven but to design, manufacture, and implement a clean burning cook stove that can help improve the standard of living.

6.2 Environmental Impacts

Pollution produced from cooking indoors ranks as the tenth most preventable risk factor contributing to global diseases and is the sixth leading risk factor for deaths in developing countries.[25] The most common effects of inhaling burning wood exhaust are chronic lung diseases, acute respiratory infections, cataracts, blindness, and birth defects.[26] The fact that this issue could be almost completely prevented with the implementation of an affordable, clean-burning cook stove led us to feel very passionately about our project.

The first and foremost necessity of families in Nicaragua is air. Clean air is essential to a long and healthy life so it is extremely unfortunate that in order to cook food clean air must be sacrificed. Women commonly cook for their families and spend an average of four hours a day doing so, constantly inhaling the toxic exhaust expelled from burning wood.[27] However, the mother is not the only family member affected by the pollution - many others are usually present while cooking takes place. “A mother of six [said] that a number of her children have battled pneumonia that required treatment at Clínica Verde, a nearby non-profit clinic,” writes Bryce Gray. Because exposure to household air pollution almost doubles the risk for childhood pneumonia[28], cooking conditions for families living in rural Nicaragua must be improved.

Implementation of a clean-burning cook stove will reduce pollution released from biomass combustion. The gasification process in the stove burns the wood fuel and also reignites the wood-gas at the top of the cook stove, burning away any remaining pollutants. It has been

[25] Clark, M. L. et al.
[26] Decker, Kris.
[27] *The World Bank.*
[28] *World Health Organization.*

proven through testing of a clean-burning cook stove intervention in Nicaragua that indoor fine particulate matter can be reduced by 77%.[29] This leads to the reduction of blood pressure levels, respiratory illnesses, and premature deaths.

Indoor cooking has extremely significant effects on the environment. Wood is the most common form of fuel for families living in rural communities because it is readily available around their homes. Families collect debris for fuel and start and control the fire in the cook stoves themselves. A very inefficient cooking method results in the loss of 85% to 90% of the wood's energy content to the environment outside the cooking pot.[30] Therefore, burning of wood not only results in indoor pollution that can have grave effects on a family's health, but also releases greenhouse gasses into the atmosphere.

About 730 million tons of biomass are burned each year in developing countries. Burning of this amount of biomass releases 1 billion tons of carbon dioxide to the environment.[31] This massive amount contributes significantly to rising global temperatures. Other products of wood combustion include black carbon, or sooty particles, and methane which are also powerful climate change pollutants.[32]

Because current cooking methods are very inefficient, the amount of wood necessary to cook a meal is much greater than it could be. Rudimentary biomass stoves used in rural communities release 50 times more pollutants and consume 6-7 times as much fuel as gas stoves in cooking the same meal.[33] Families have to spend much of their time searching around their homes for as much wood fuel as they can find to ensure they have enough cooking power. So, use of these stoves has also led to deforestation, soil erosion, and desertification.[34]

Team Forge 2.0's goal is to produce a more efficient, functional cook stove that releases much less pollutants to the environment. This cook stove will alleviate the environmental consequences of indoor cooking pollution. Currently, the effectiveness of our design team's cook stove to reduce harmful, gaseous pollutants through the gasification process is not quantified.

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[29] Clark, M. L. et al.
[30] Ecker, Kris.
[31] *The World Bank.*
[32] *World Health Organization*
[33] Staton, Donna M. and Marcus H. Harding.
[34] Decker, Kris.

From testing and the acquisition of a TSI Condensation Particle Counter, model 3007, the change in particulate matter in the exhaust of our stove was measured for various burn conditions. This was used as a metric to evaluate the performance of the stove as an emissions-reducer as compared to traditional cook stoves.

One feature of burning biomass is the creation of ash. In a wood-fueled stove, the product of the burn is in the form of charcoal, which when used as a soil additive is called biochar. Biochar contains potassium, phosphorus, calcium and magnesium, and a report from Ohio State University reports that biochar is half as effective as lime as an acid-neutralizing agent.[35] Gardens with fruit trees, shrubs, vegetables and bulbs benefit from neutralization of acidic soil.

6.3 Sustainability

Current cooking conditions give rise to sustainability issues dealing with natural resources. Team Forge's cook stove is much more sustainable than the stoves being used today. It is important to address these points because increased sustainability can result in a more affordable cooking method for those living in Nicaragua.

As stated in the previous section, most of the energy produced from wood fires is lost to the environment. For three-stone fires, which are commonly used in developing countries, thermal efficiency is stated to be as low as 10 to 15%.[36] Therefore, much more wood needs to be collected than if the cook stove performed more efficiently, leading to an extreme waste of natural resources. An improved cook stove would be much more sustainable by requiring less wood fuel and more effectively using the heat produced.

Team Forge 2.0's cook stove is not only more efficient than current stoves, but it is also a more sustainable product in itself. It is made of mild steel which is known to withstand extremely high temperatures for many cycles of use. Therefore, the product has a long lifespan and requires little to no modifications with time. Once the product is no longer being used, the stove's materials can be recycled. Steel is the most recycled material in the world - new steel is

[35] Hume, Ed.
[36] Decker, Kris.

produced from two-thirds old steel and one-third virgin materials.[37] Manufacturing our cook stove out of mild steel has allowed for a much more sustainable product.

6.4 Ethical Impacts

Our design team felt an ethical duty to use the education we were given to help those who lack the sufficient resources and economy to live at a higher standard of living. The United States comprehensive federal law, the Clean Air Act of 1970, regulates air pollutants from both stationary and mobile sources. This law gives the EPA authority to establish the National Ambient Air Quality Standards in order to protect public health and welfare and regulate the hazardous air emissions. Since developing countries do not yet have the infrastructure to host such laws, it is our duty to help those in need and protect our planet. Helping to clean the air will in turn saves lives not only in the short term but also long into the future. Team Forge 2.0's clean-burning cook stove does this by ridding our environment of harmful emissions which seek to destroy the ozone layer which protects us from the sun's radiation.

6.5 Health and Safety Impacts

The two most prominent issues regarding health and safety that arose from this project are the possible production of harmful pollutants associated with burning organic fuels and the dangers of high temperatures.

Existing cook stoves in Nicaragua are often nothing more than open-air fires with a clay or brick structure around them to aid in insulation.[38] The smoke produced can be piped out of a roof through a chimney, but existing homes often have to be altered to accommodate this process which is sometimes not a viable option. The implementation of a clean-burning stove will eliminate the need for a chimney and allow users to cook inside their homes without worrying about respiratory problems arising from the inhalation of exhaust. This means that the users will not have to alter their homes in order to use the stove and the overall health risks to the family

[37] *Steel Works: The Online Resource for Steel.*
[38] Kinne, Susan.

and condition of the home will be improved. Existing cook stoves often produce carbon buildup on the walls of the home, discoloring them with soot.

The table below provides quantitative data regarding the health risks that come with household air pollution.

Box 3. Household air pollution linked to multiple health risks

A new study on the global burden of disease shows household air pollution is related to a variety of illnesses. In its assessment of peer-reviewed medical studies over the past 15 years, the study found increased health risks for acute lower respiratory infection (ALRI), chronic obstructive pulmonary disease (COPD), cataracts, lung cancer, and cardiovascular disease. The increased probability of contracting such illnesses ranged from 78 percent for ALRI in children under 5 to more than 150 percent for COPD in women over 15 (table).

Increased probability of various illnesses by population group

Health outcome	Sex/ category	Age (years)	Range of reported increase in risk (%)
ALRI	Male and female/ children	< 5	45–118
COPD	Male/adults	> 15	95–275
COPD	Female/adults	> 15	15–213
Cataracts	Female/adults	> 30	61–273
Lung cancer	Female/adults	> 15	7–206

The medical studies analyzed were subjected to a strict set of measurement criteria to assess the validity and relevance of their findings.

Source: Smith, Bruce, and Mehta (2010).

Figure 6.1: Results of a global study regarding increased health risks due to household air pollution.

Any form of cooking inherently produces danger due to high temperatures. Existing cook stoves in Nicaragua often employ different forms of insulation which are dual purpose. Insulation in the form of earthen material reduces heat loss to the environment and improves cooking efficiency, while also reducing the temperature of the outer surface of the stove. Team Forge 2.0 desired to produce a design that limits exposure to open flame while also reducing temperature of the outer surface. However, because of the improved air flow of the design, temperature of the cooking fire reaches temperatures over 700°C, and the outer surface temperatures range from 200-300°C. It is necessary for users to protect themselves if handling the stove shortly after operation by means of insulation such as thick gloves.

For this reason and the others previously explained, Team Forge 2.0 provides an instructional pamphlet with the stove which employs pictorial information to warn its users of the potential dangers. The pictures are captioned in the native language, Spanish, to ensure no information is lost in translation.

Chapter 7 – Summary and Conclusion

Overall our manufactured design met most of our initial criteria and we were successful in quantifying the results of last year's design and reducing the particulate emissions by about 8%. The addition of a lower row of secondary inlets proved to be a sleek modification to last year's design without adding any cost. The air flow regulator, although effective, is not as elegant as our design team would have liked it to be. The design is smaller than our design team believes would be preferable for large family style cooking, but making the stove larger would have increased the price to far beyond our user's means. Additionally, our design team believes our stove to be too high maintenance for our users as our design team was removing and grinding the chimney before each burn. In reality, this proactive measure would not be done before each burn. The design achieved our design team's goals, however, there are areas of the design that need to be refined before the product is ready for implementation.

Even though the experimental results show a particulate matter reduction of about 8% compared to last year's design, there is still much room for improvement. Our design team's results indicate more secondary inlet holes would further the gasification process if regulated properly. We propose a third or even fourth row of secondary inlet holes that can be regulated individually along with the existing two rows. The addition of these secondary inlet rows would allow the air flow to be regulated more continuously as the burn progresses. We also suggest the chimney be manufactured as one with the combustion chamber to ease user setup and cleanup activity. Manufacturing the stove as one continuous part would increase user centricity of the design without changing any of the inner workings of the stove or its capabilities. Additionally, regarding usability, making the air flow regulator an automatic mechanism would cut out user interactions with the regulator completely. This action would reduce a user's risk of coming into contact with hot metal and could also improve performance if the mechanism could accurately sense high temperatures located at the levels of the secondary inlets. In order to fully understand the benefits of this design, it is still necessary to obtain quantitative data pertaining to the harmful, gaseous emissions of produced by Team Forge 2.0's stove compared to a traditional open fire.

This design team learned many that tests need to be made in order to obtain usable data.

Time is not often permitting of inconclusive results and it was very fortunate that the Santa Clara University Environmental Department allowed the use of their equipment after many initial tests failed to produce any usable data.

Be proactive throughout the process and stick to the timeline as best as possible. Our design team often let too much time pass and missed deadlines that were set for ourselves because we were waiting on replies or services from third parties. If possible, reach out to contacts in person so activity does not stall if an important email goes unanswered.

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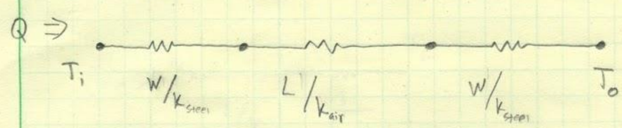
APPENDIX A – Detailed Calculations

Assumptions: Steady-State, constant material properties, 1-D radial heat transfer, no radiation

From testing,



$T_i = 1000\,K$

$T_o = 450\,K$

k_{steel} @ $450°K = 55.7\ W/mK$ $\quad W = .003048\,m$

k_{steel} @ $1000°K = 32.3\ W/mK$ $\quad L = .05715\,m$

k_{air} @ $725°K = 56 \times 10^{-3}\ W/mK$

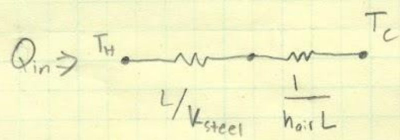
$$R_{tot} = \frac{.003048m}{55.7\ W/mK} + \frac{.05715m}{(56\times10^{-3})\ W/mK} + \frac{.003048m}{32.3\ W/mK}$$

$$R_{tot} = 1.0207\ K/W$$

$$Q = \frac{T_i - T_o}{R_{tot}} = \frac{550K}{1.0207\ K/W} = 538.8\ W$$

Figure A.1: Heat output calculation.

Assumptions: Steady-State, Constant material properties, no radiation



Because k_{steel} will change over the length through which the conduction occurs, an averaged value will be used in this calculation. From testing, the temperature of the top of the combustion chamber is known (T_H) to be 500 K. The bottom of the outer chamber of the stove was observed to be at ambient temperature throughout the cooking process. Direct conduction occurs down to the bottom of the combustion chamber, T_C. Due to its proximity to the outer chamber at T_∞ and the direct conduction, the k_{steel} value is determined using $T_H = 500\,K$ and $T_c = 325K$.

k_{steel} @ 412.5K = 56.8 W/mK $\qquad$ $h_{air} = 20\ W/m^2K$

$L = .308\,m$

$Q_{in} = 538.8\ W$ (from prior calculation)

$$R = \frac{L}{k_{steel}} + \frac{1}{h_{air} L} = 0.16776$$

$$Q = \frac{T_H - T_C}{R} \Rightarrow Q(R) - T_H = -T_c$$

$$538.8(.16776) - 500 = -T_C$$

$$T_C = 409.61\ K$$

Figure A.2: Temperature calculation.

APPENDIX B – Detailed and Assembly Drawings

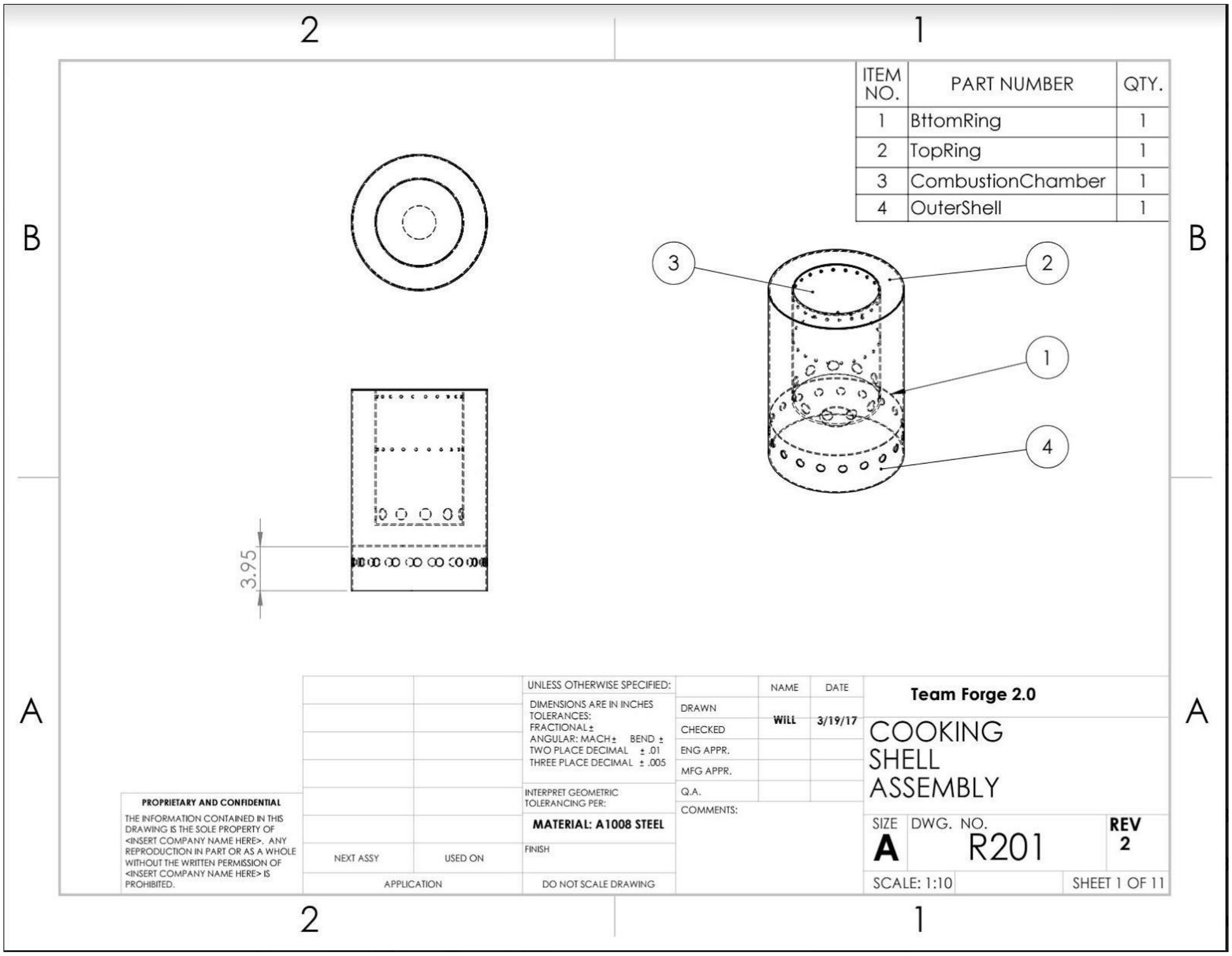


Figure B.1: Cooking Shell working drawing.

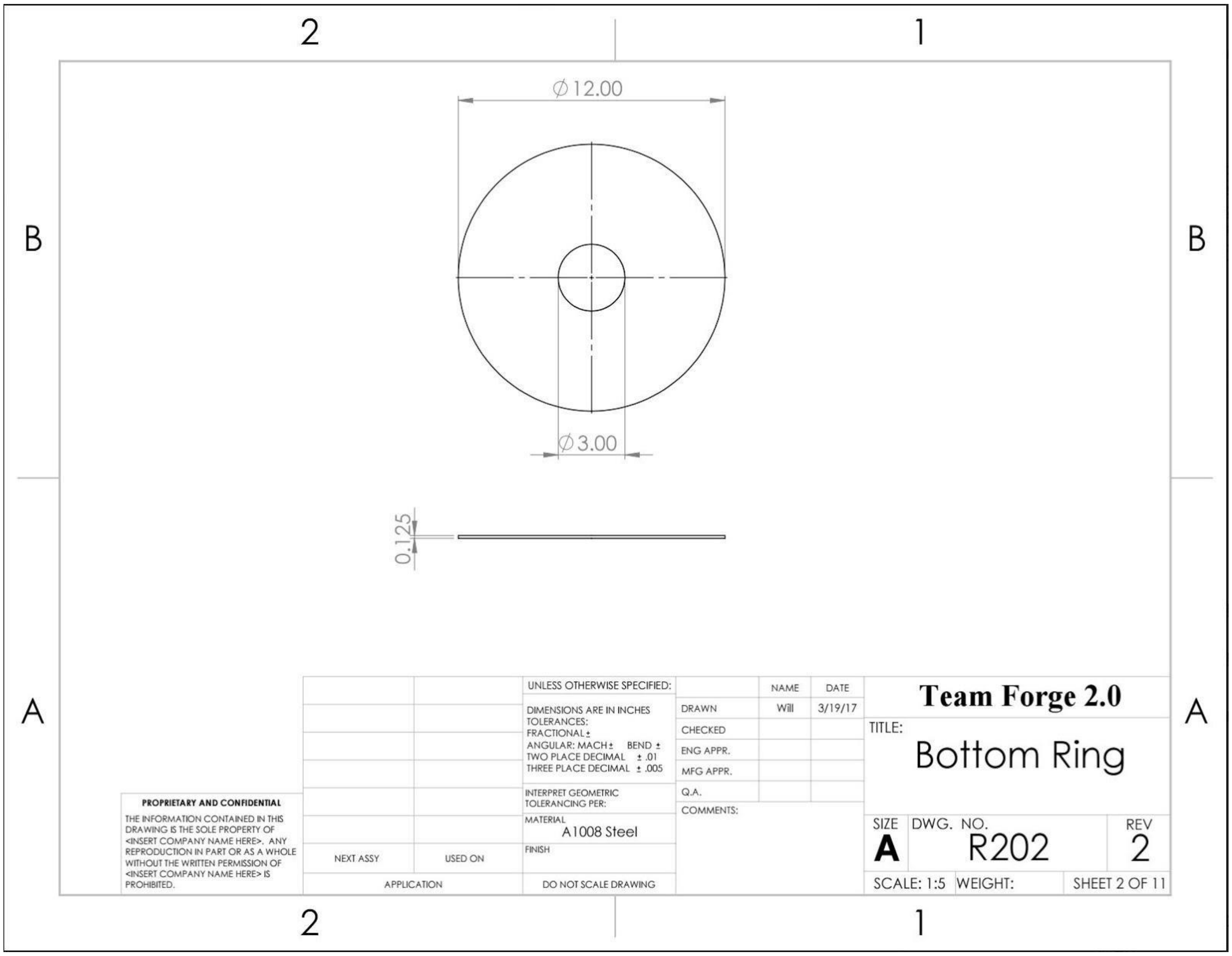


Figure B.2: Bottom Ring working drawing.

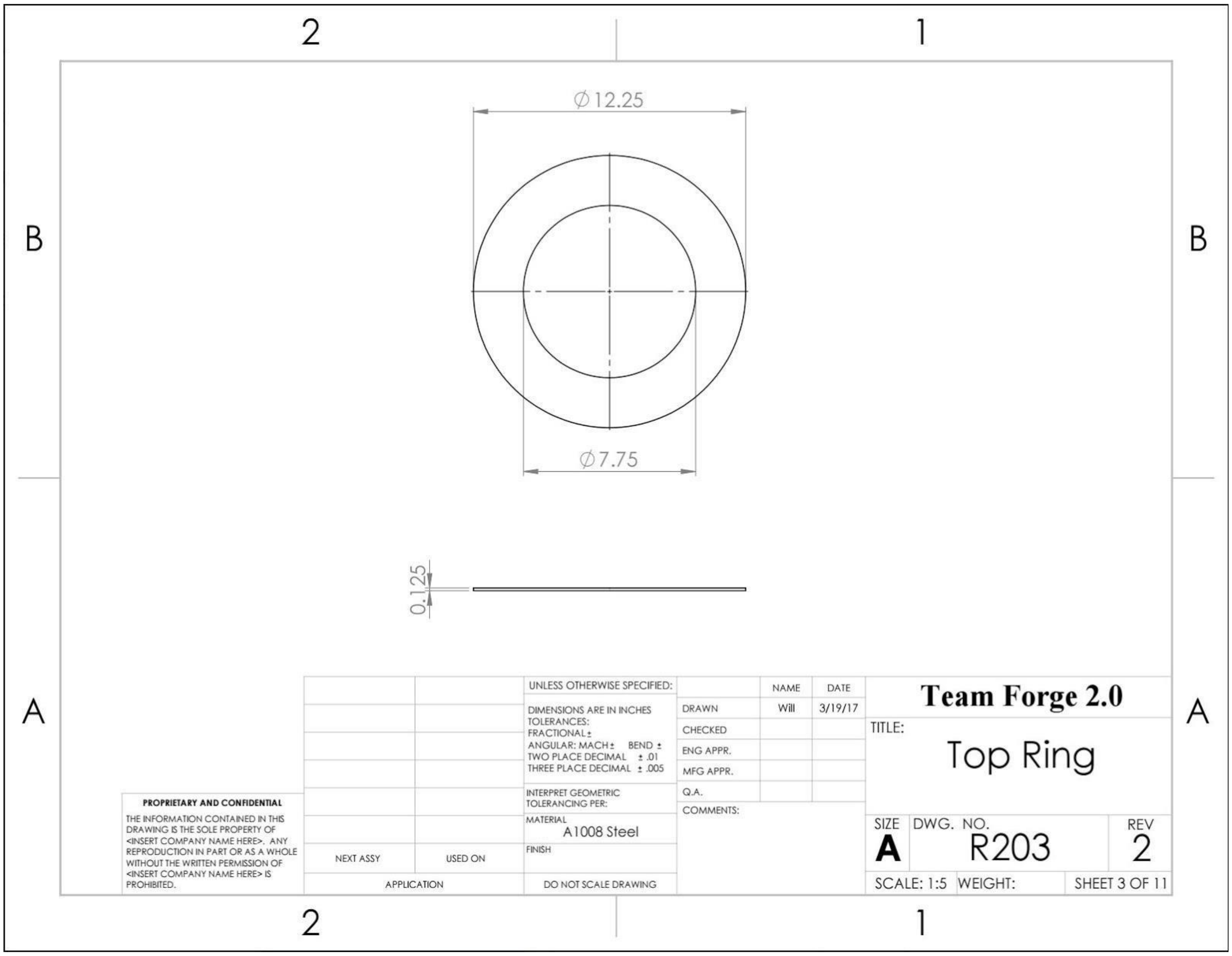


Figure B.3: Top Ring working drawing.

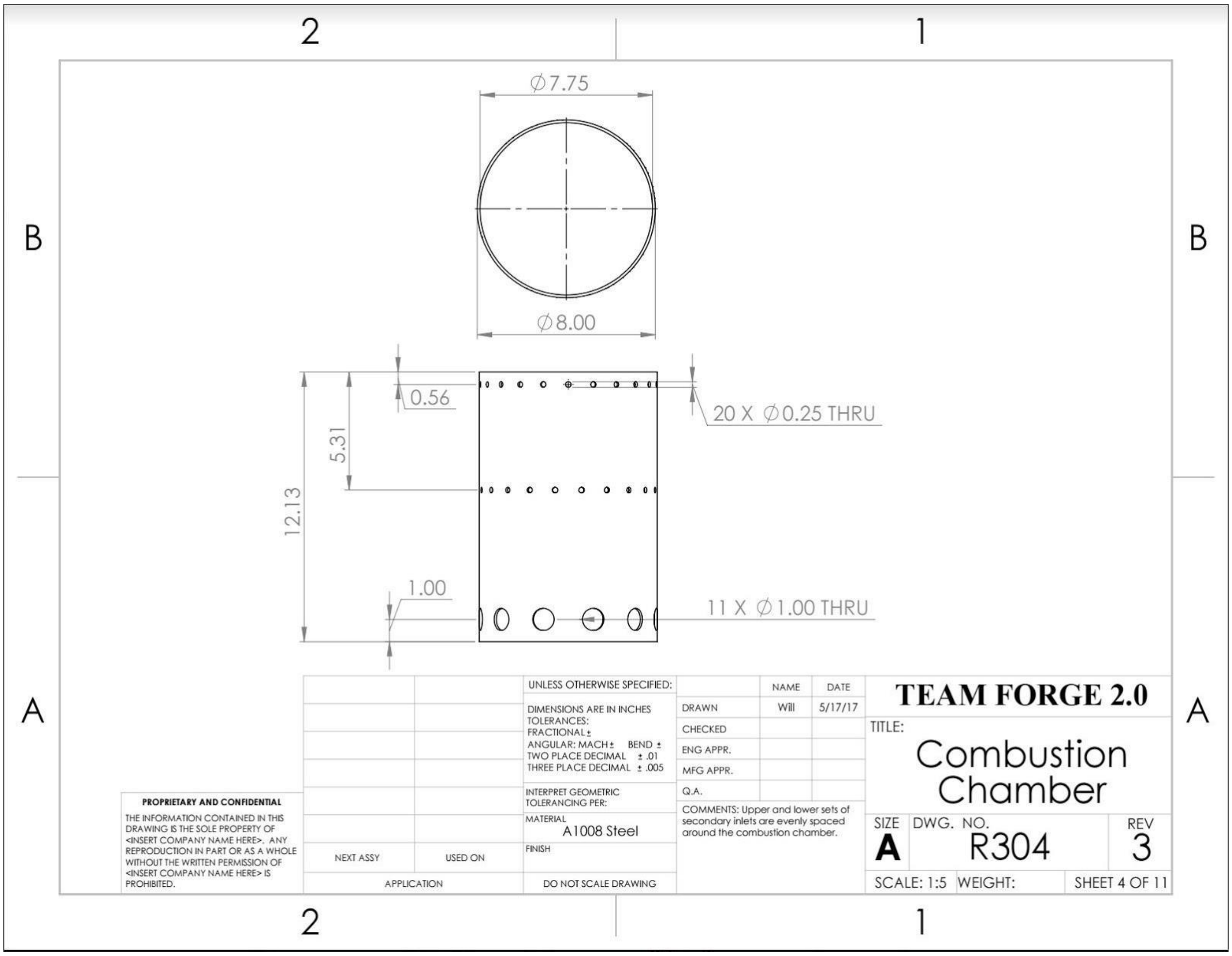


Figure B.4: Combustion Chamber working drawing.

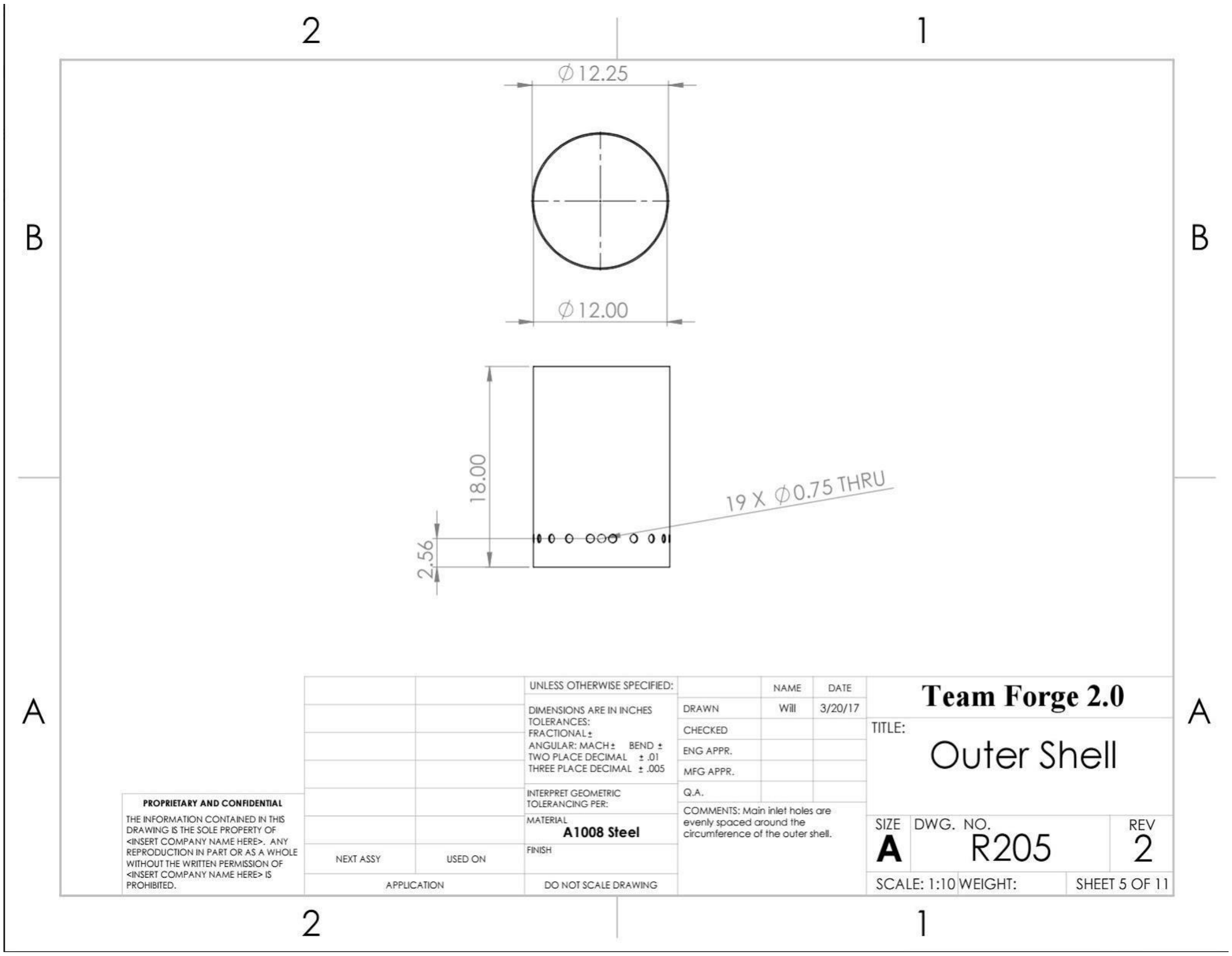


Figure B.5: Outer Shell working drawing.

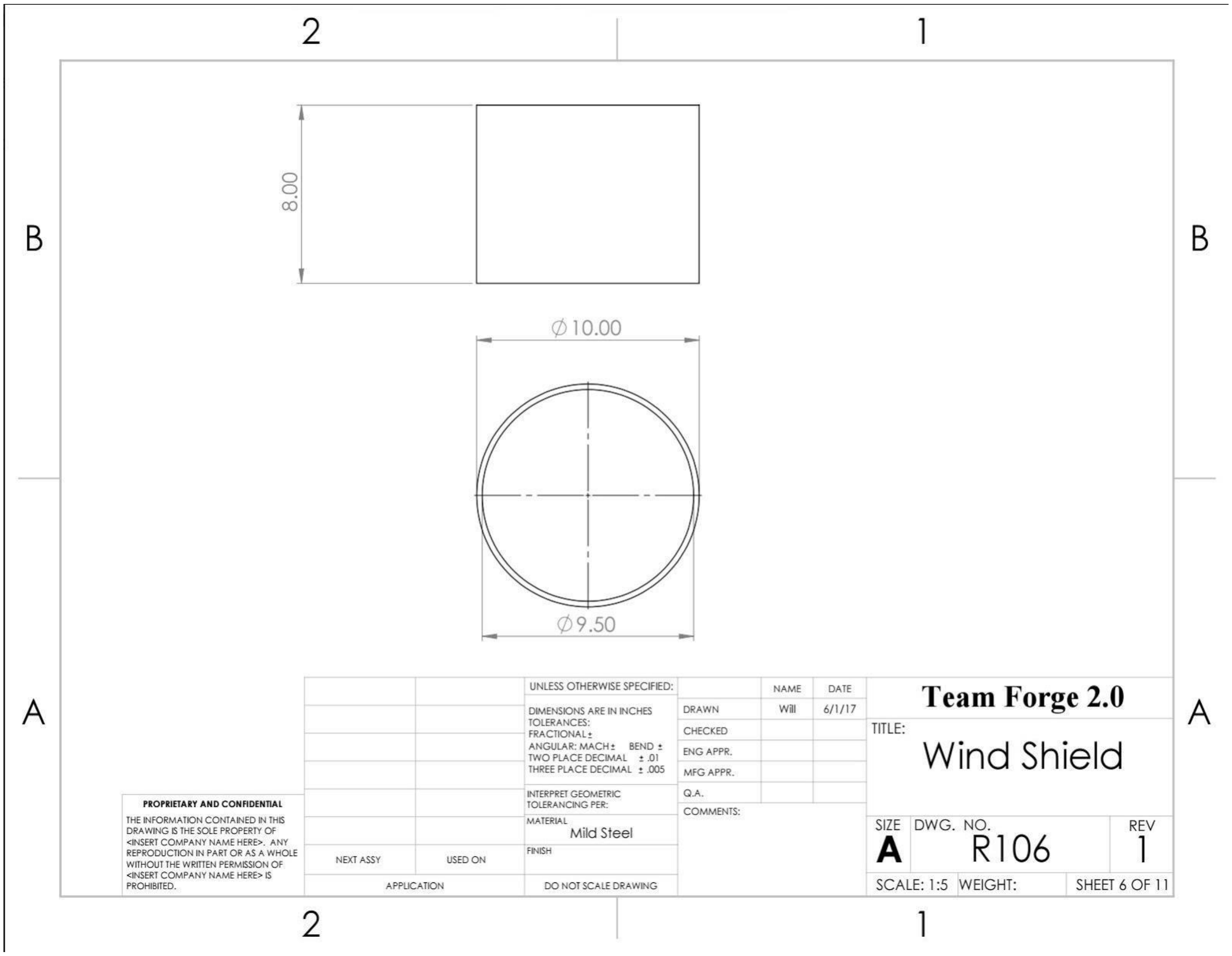


Figure B.6: Wind Shield working drawing.

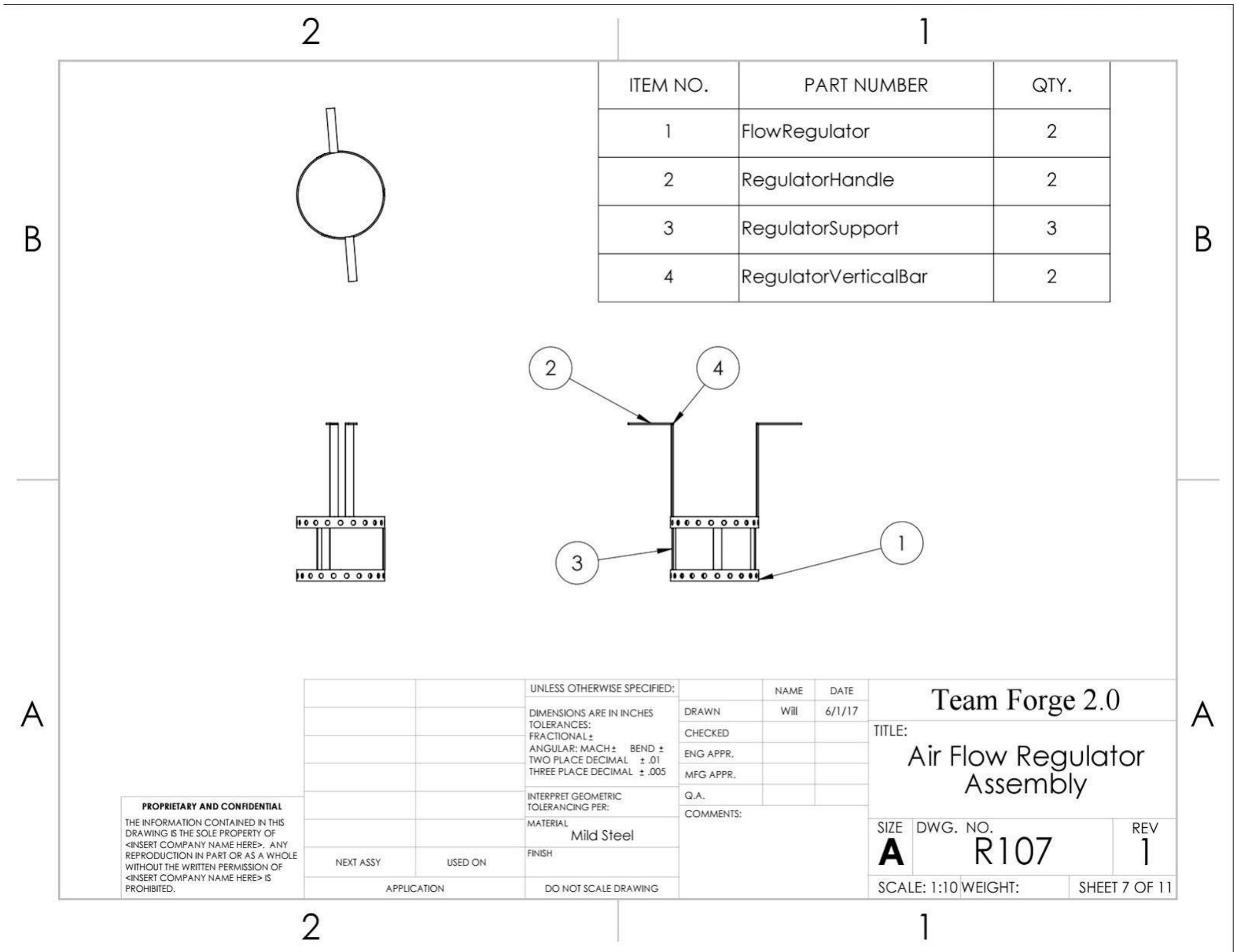


Figure B.7: Air Flow Regulator Assembly drawing.

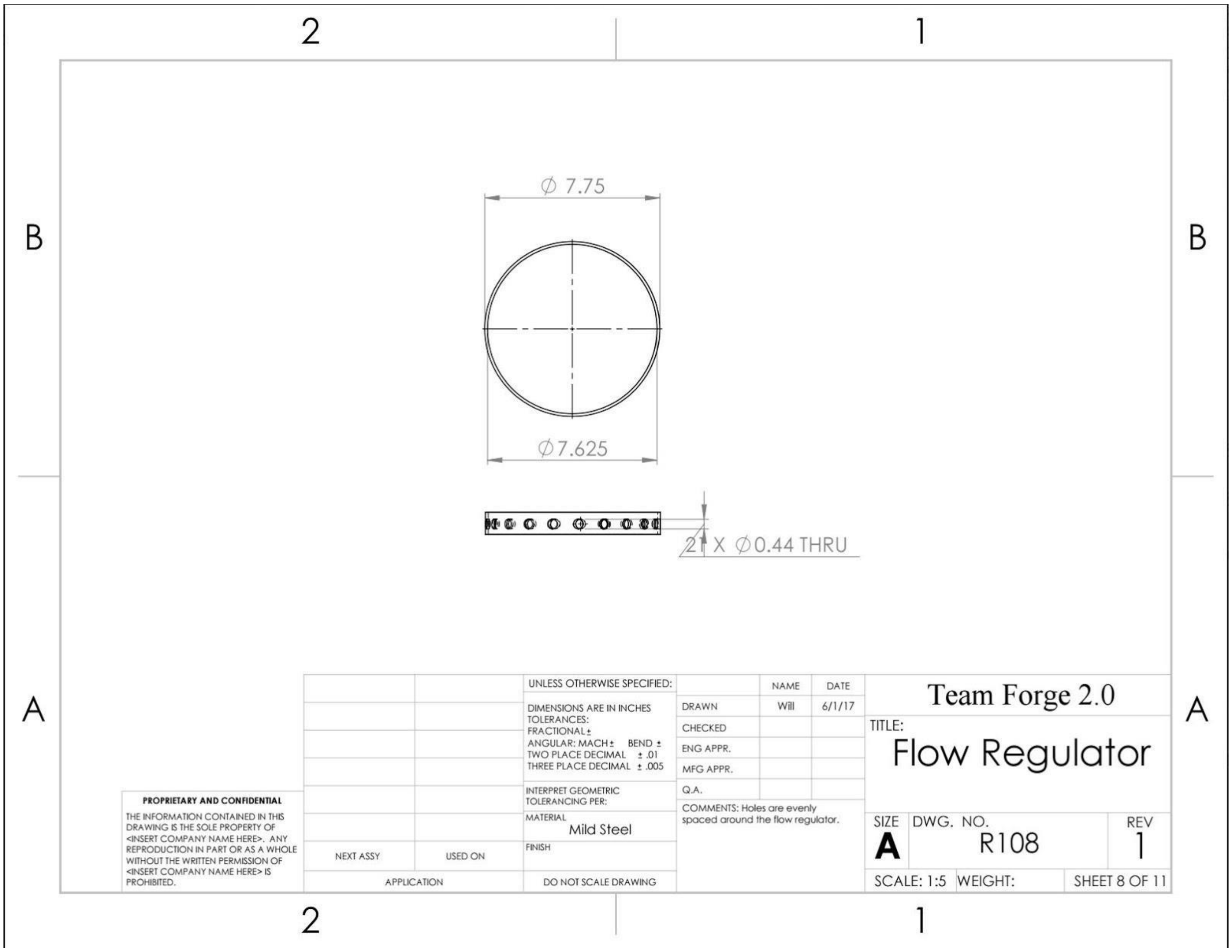


Figure B.8: Flow Regulator working drawing.

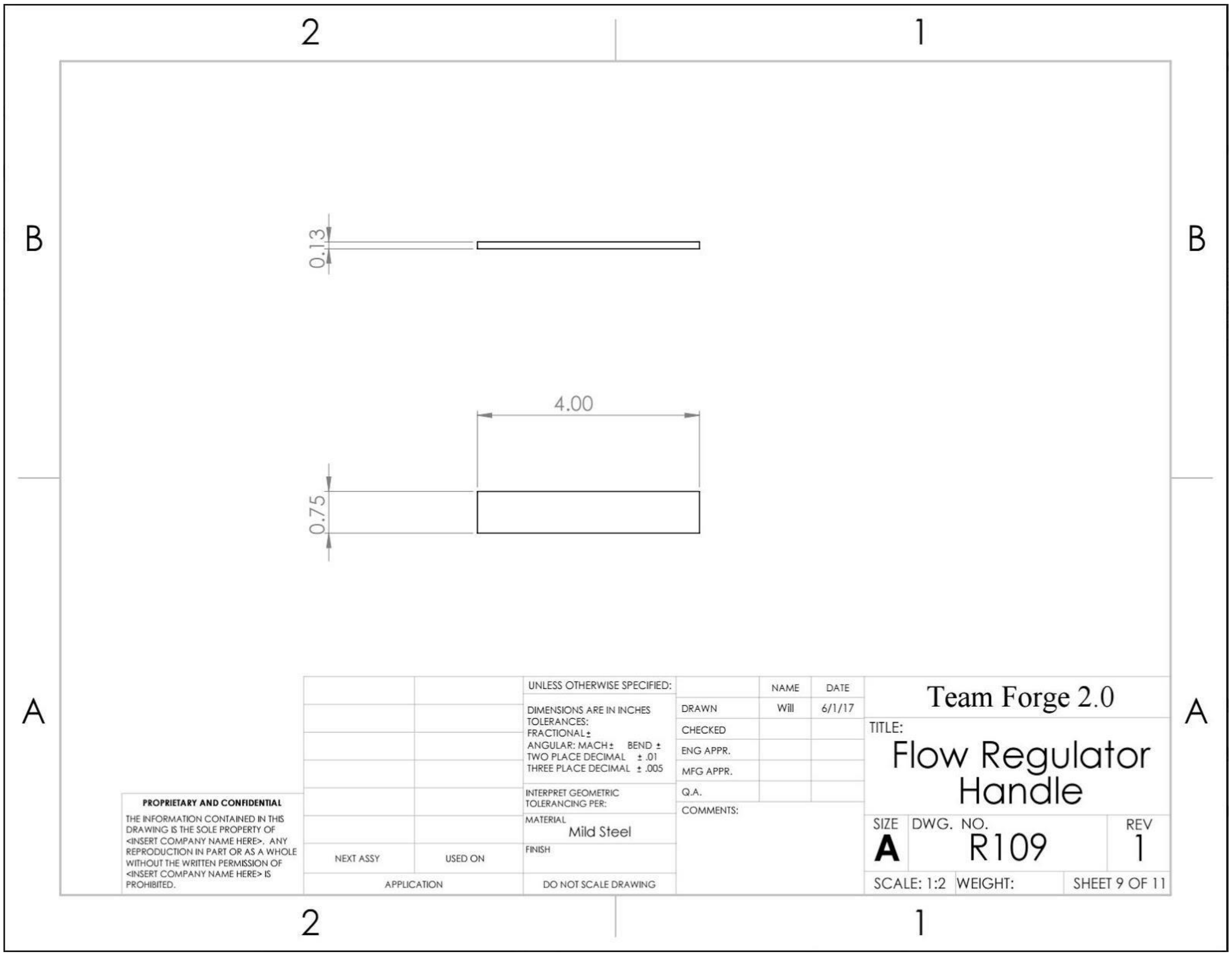


Figure B.9: Flow Regulator Handle working drawing.

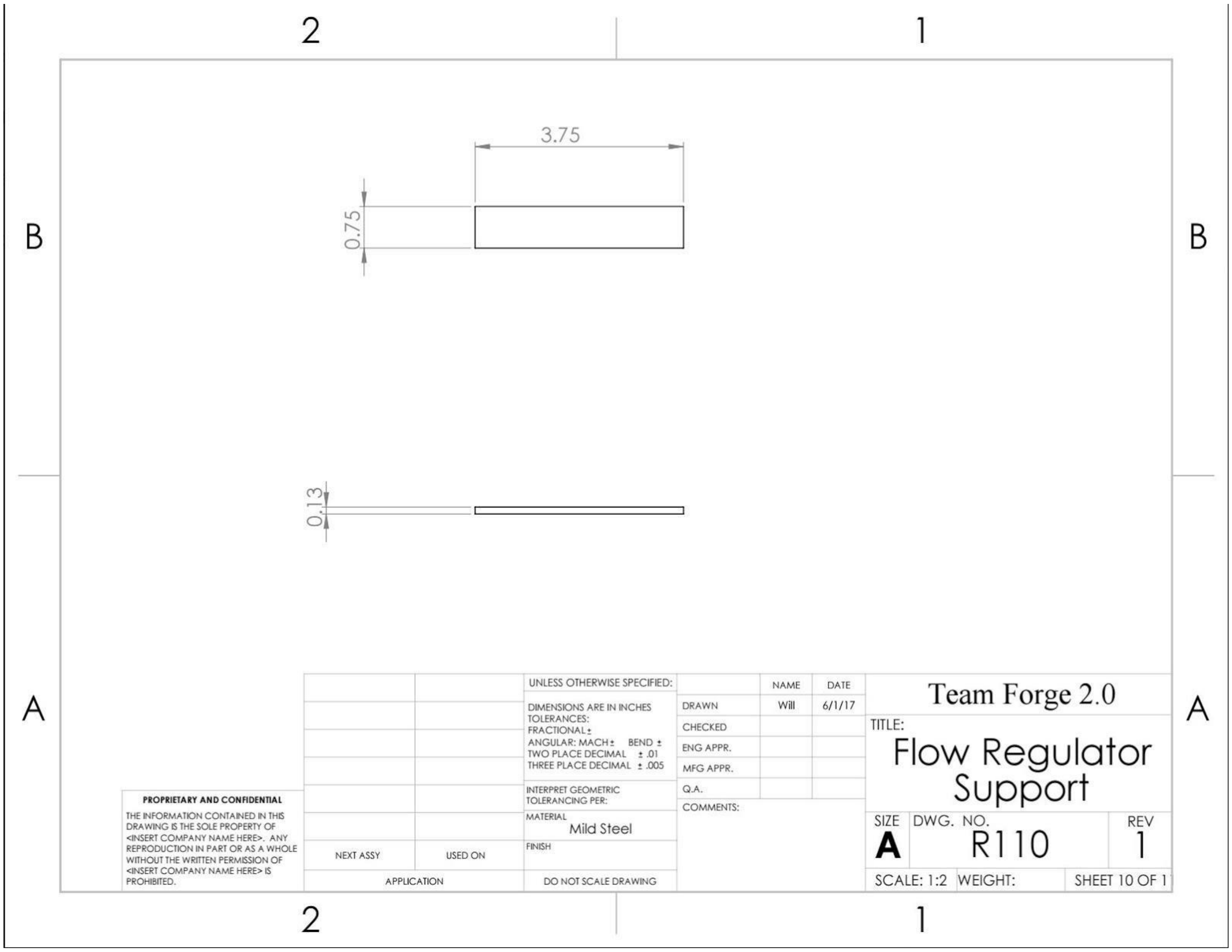


Figure B.10: Flow Regulator Support working drawing.

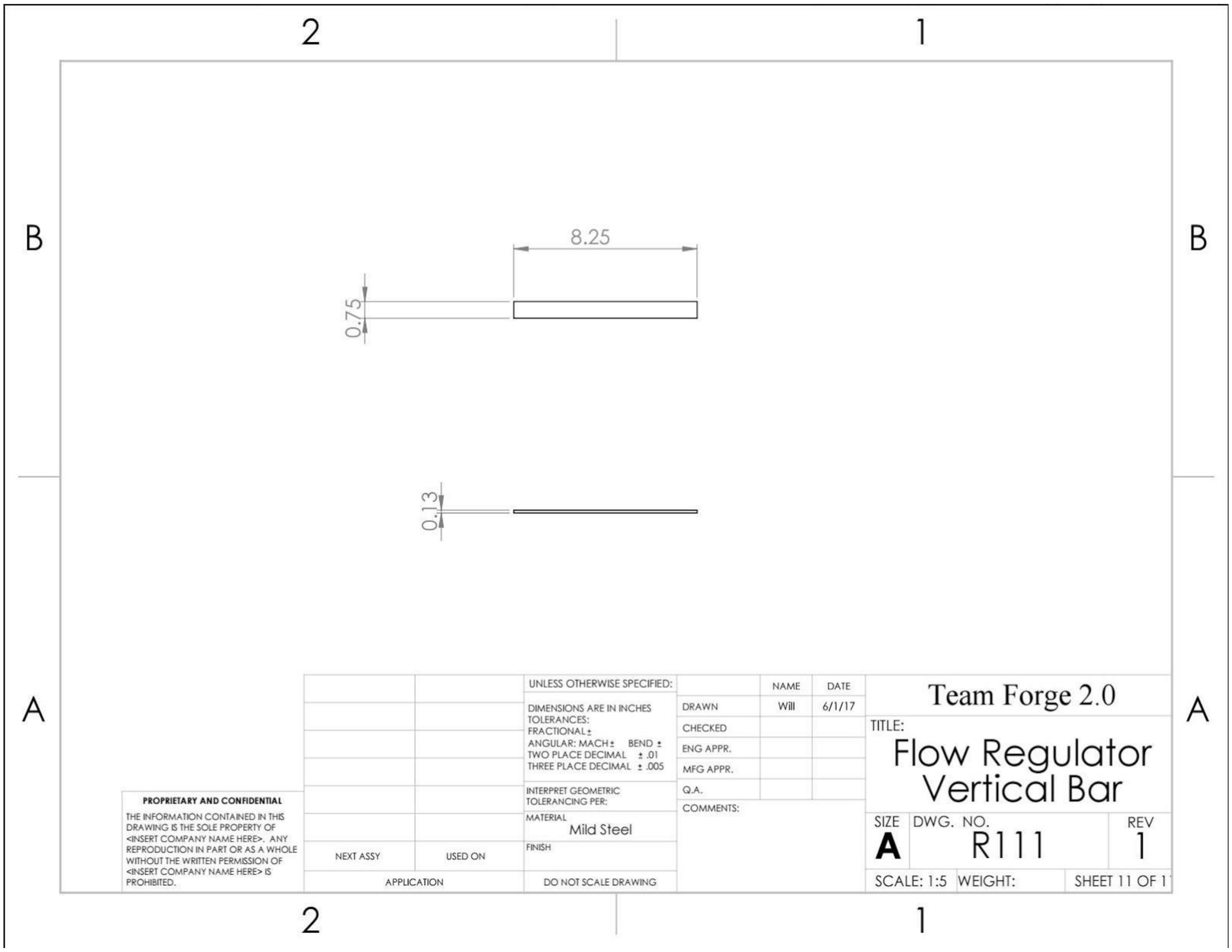


Figure B.11: Flow Regulator Vertical Bar working drawing.

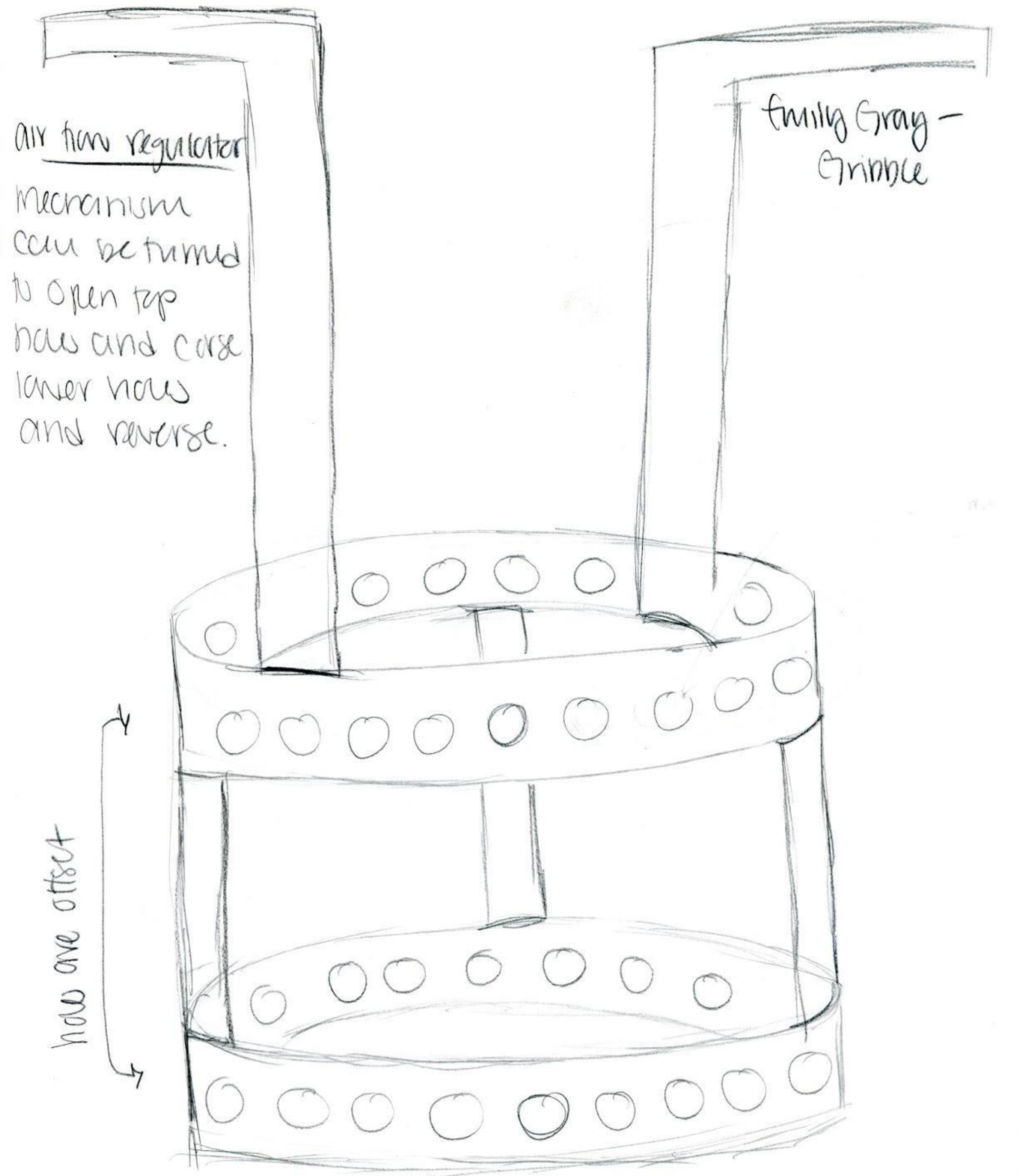


Figure B.12: Air Flow Regulator attributed drawing - Emily Gray-Gribble.

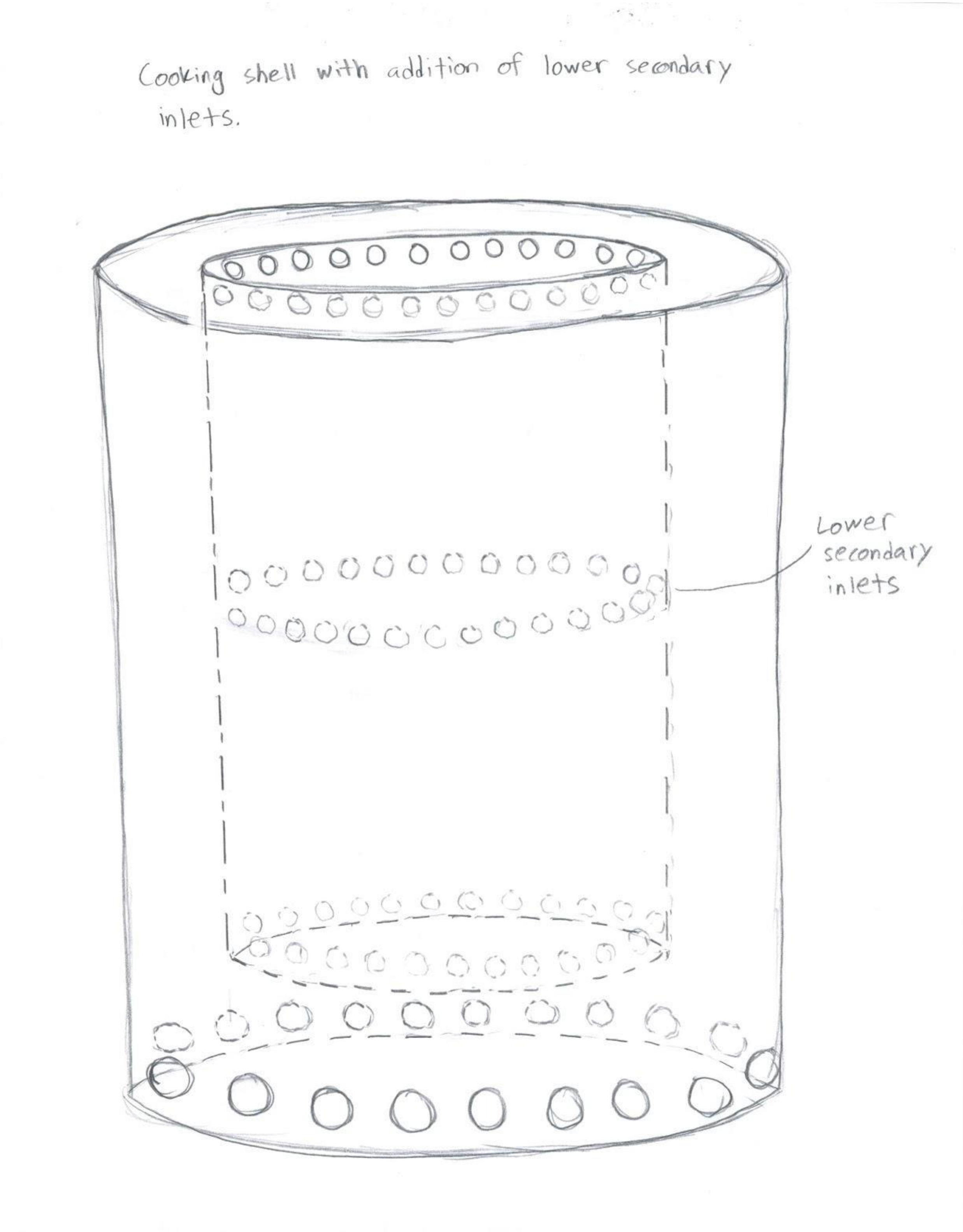


Figure B.13: Modification of cooking shell attributed drawing - Will Gebb.

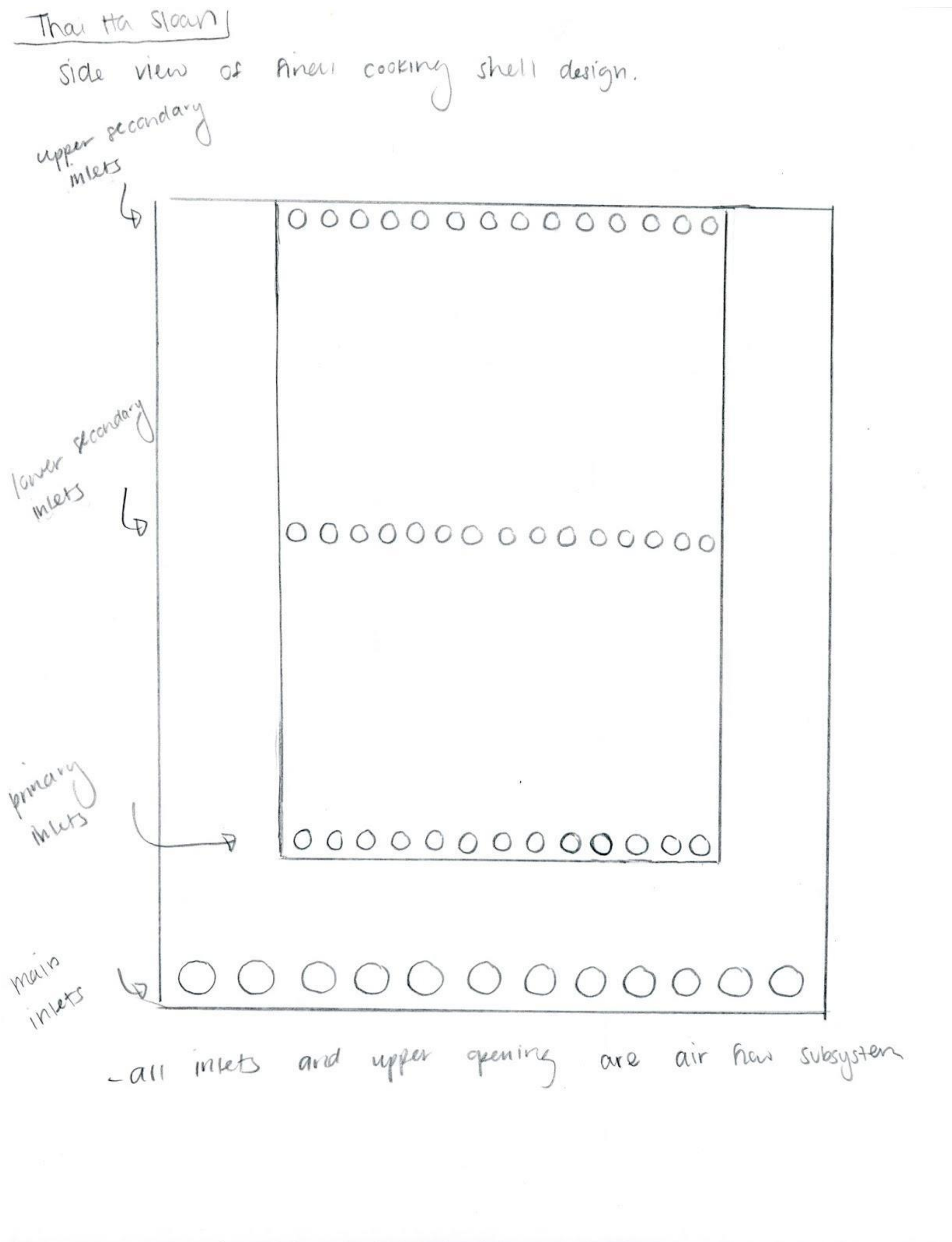
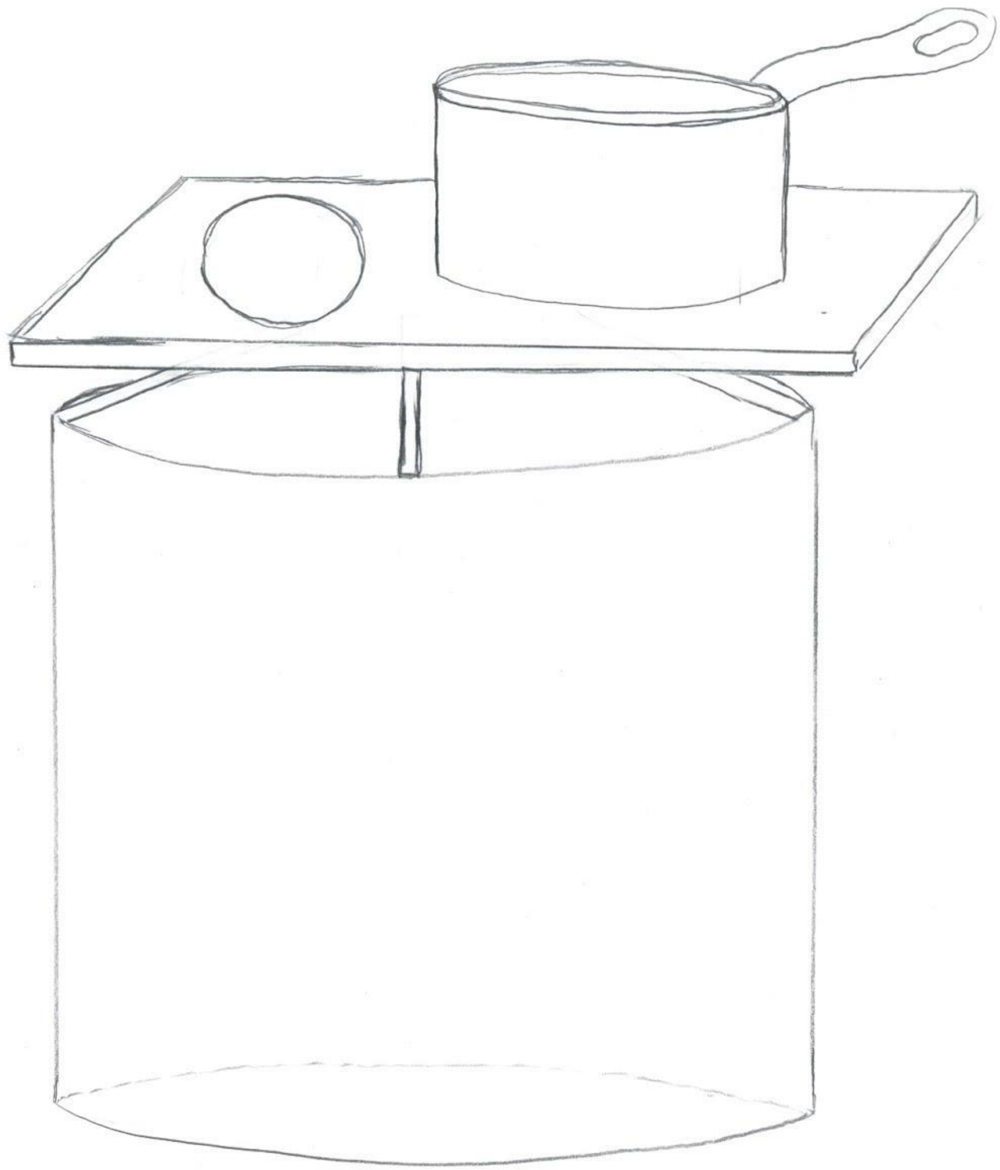


Figure B.14: Cooking Shell attributed drawing - Thai Ha Sloan.



Cooking Surface with stove. The cooking surface is placed on top of metal risers that allow for airflow & heat transfer from fire to cooking surface

Figure B.15: Cooking Surface attributed drawing - Matthew Lee.

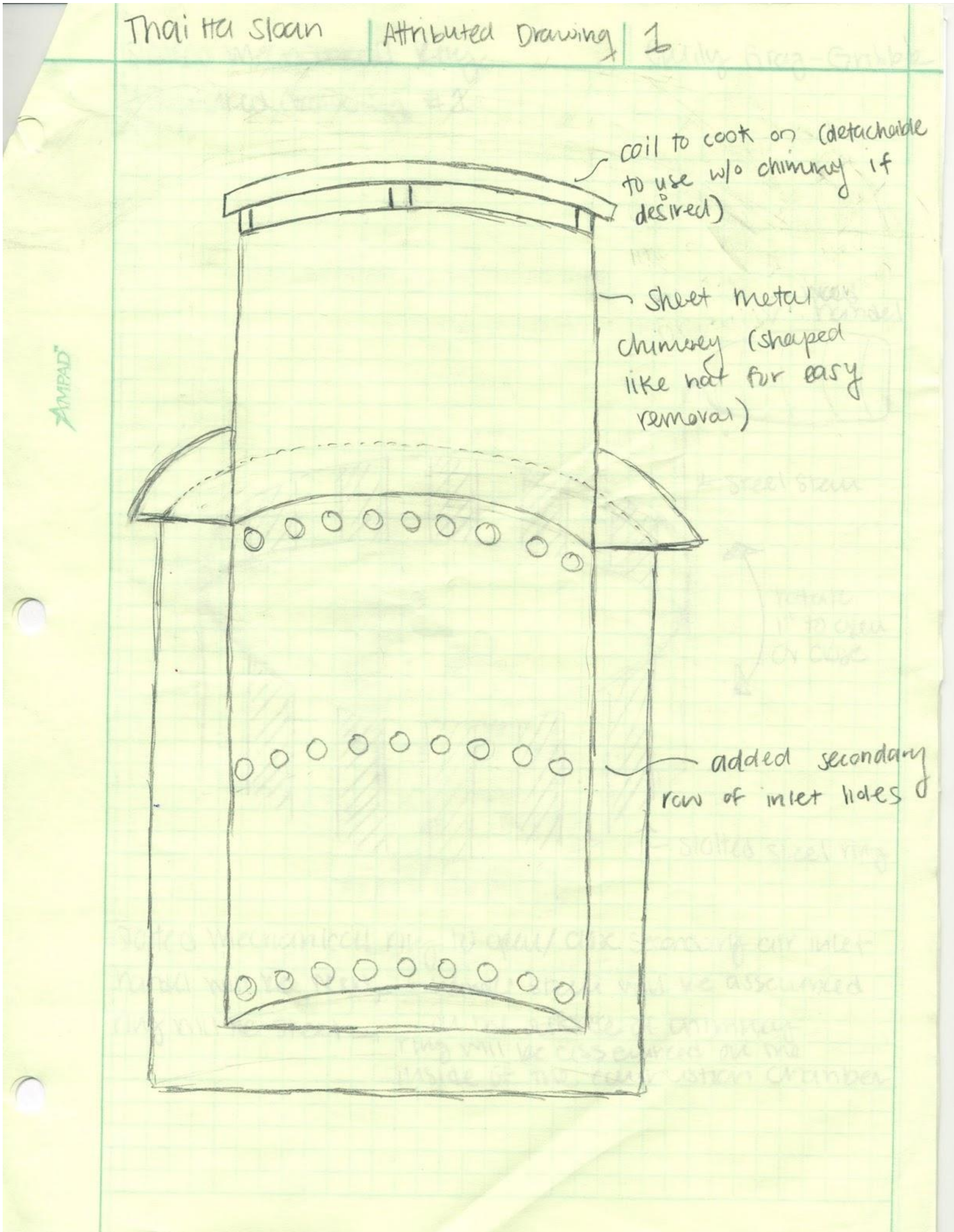


Figure B.16: Forge 2.0 stove side view attributed drawing - Thai Ha Sloan.

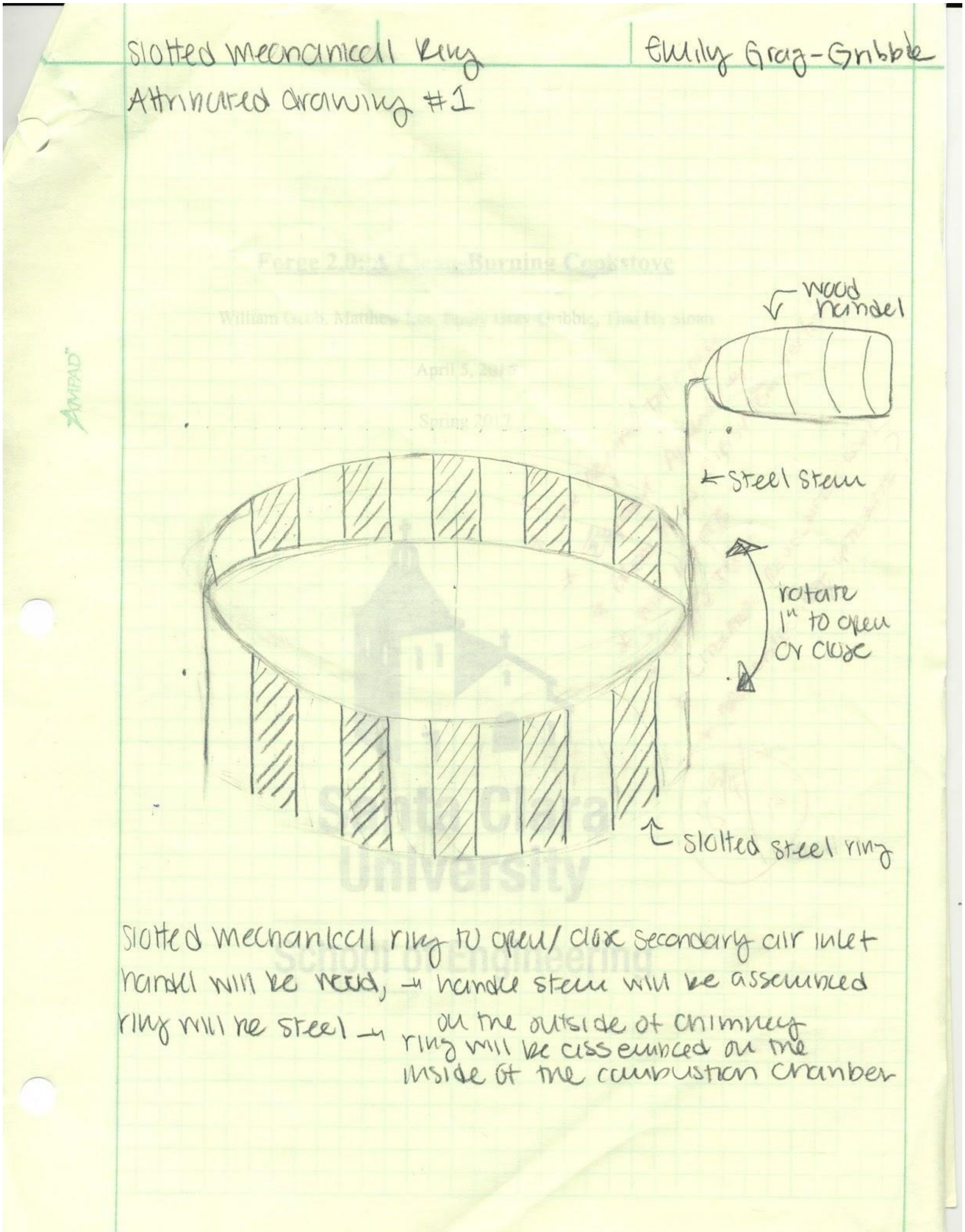
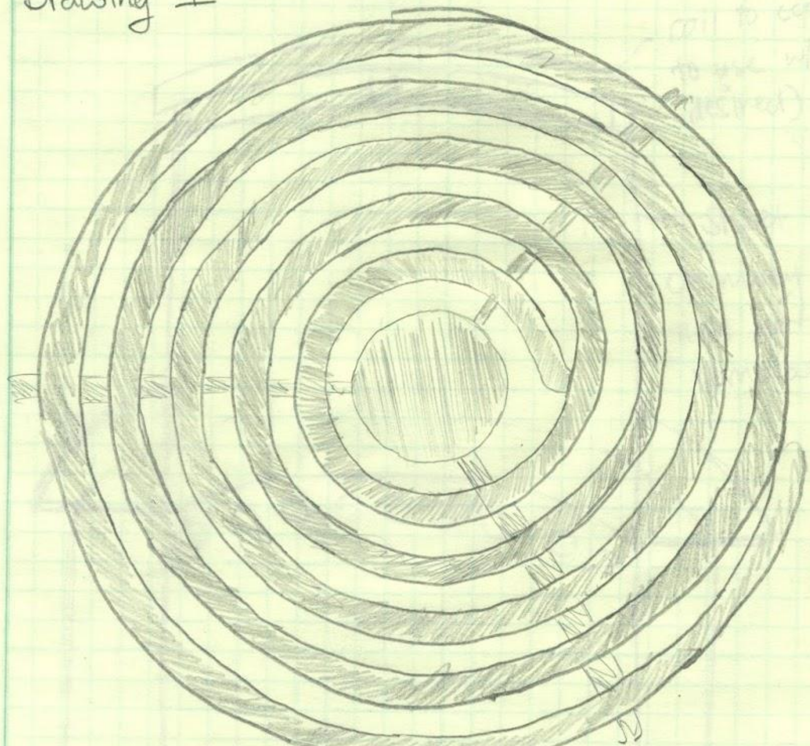


Figure B.17: Initial Air Flow Regulator attributed drawing - Emily Gray-Gribble.

Top Cooking Surface | MATT LEE

Attributed Drawing 1



TOP VIEW OF COOKING surface

↳ detachable cooking surface that can be placed on top of the stove to safely cook food on top of

Figure B.18: Initial Cooking Surface attributed drawing - Matthew Lee.

APPENDIX C – Problem Design Specifications

Table C.1: PDS Problem Design Specifications.

Requirement		Reason	Unit	Value/Range
Performance	Temperature	Achievable for cooking surface ad distribution	Celsius (℃)	700℃-1000℃
	Heat	Amount created	Kilowatts (kW)	3.41 kW
	Particulte emissions reduction factor	Determine a level of efficiency	Particles per cm^3	Reduce by a factor of 2
	Time to achieve gasification	Determine a level of efficiency	Second(s)	<120 seconds
Material Properties	Metal housing	Combustion chamber	Square meters (m^2) Inches (in)	Sheet metal 0.778 m^2 16 in diameter
		Outer shell	Inches (in)	18 in diameter
		Chimney	Inches (in)	16 in diameter
	Slotted dual mechanism	Open and close primary and secondary inlet holes simultaneously	Inches (in)	1/4 in thickness 15 3/4 in diameter
	Cooking surface	Temperature distribution	Inches (in)	16 in x 9 in
Various Requirements	Fuel size	Ensure complete combustion	Inches (in)	1.5 in -2 in
	Cost	User's low income constrains	USD	<100.00 USD
	Ergonomics	Simple mechanism required for uneducated users	N/A	User functionality as a primary concern
	Reliability	Desired elimination of particulate matter with every burn at each inlet	Second(s)	<30s to achieve gasification at secondary inlet
	Safety	Insulation	Inches (in)	0.5 in - 1 in thickness

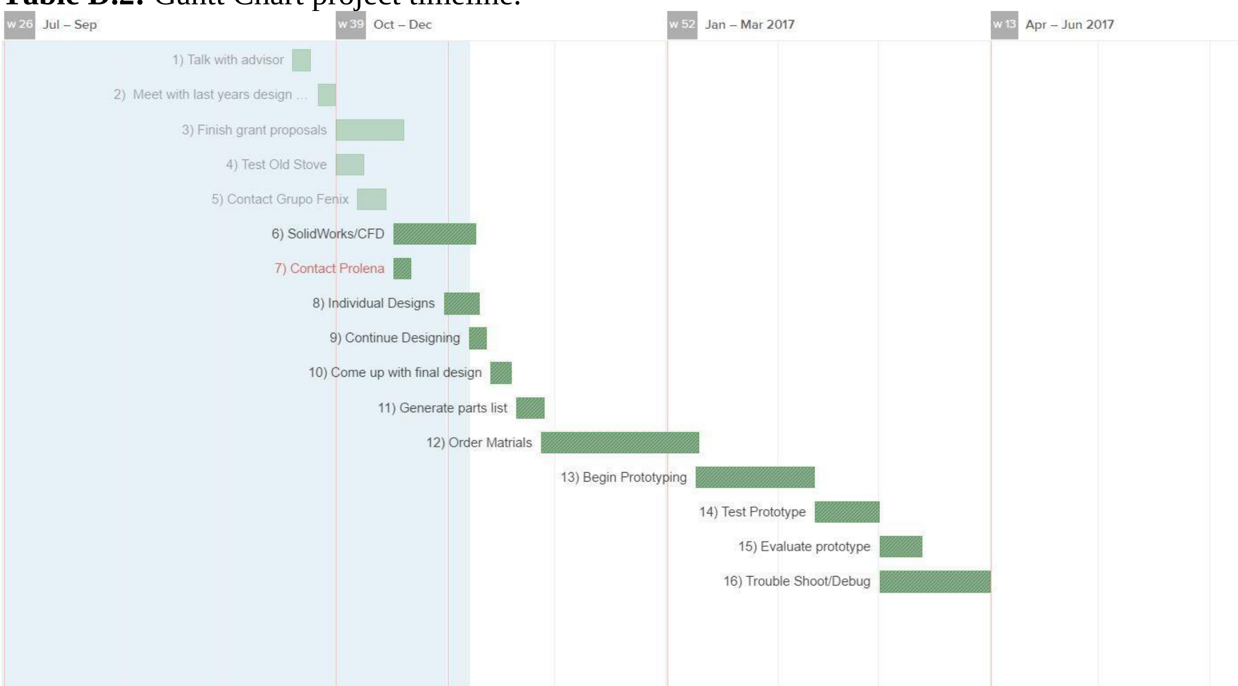
Key: Evaluation criteria.

APPENDIX D - Decision Matrices and Timeline

Table D.1: Decision matrix with weight functions.

Project:	Forge Cookstove														
System:	Overall														
Date:	8-Nov-16														
	Criterion	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	SUM	FACTOR
1	Primary Airflow		1	0	0.5	1	0.5	1	1	1	0	0		6	4
2	Secondary Airflow	0		0	1	0.5	0	1	0.5	0.5	0	0		3.5	3
3	Power Output	1	1		1	1	0.5	1	1	1	0	0		7.5	4
4	Weight	0.5	0	0		0	0	0.5	0	0	0	0		1	1
5	Cost	0	0.5	0	1		0	1	0.5	0.5	0	0		3.5	3
6	Safety	0.5	1	0.5	1	1		1	1	1	0	0		7	4
7	Aesthetics	0	0	0	0.5	0	0		0	0	0	0		0.5	1
8	Difficulty of Production	0	0.5	0	1	0.5	0	1		0.5	0	0		3.5	3
9	Stovetop Size	0	0.5	0	1	0.5	0	1	0.5		0	0		3.5	3
10	Electricity Generation	1	1	1	1	1	1	1	1	1		0.5		9.5	5
11	Pollutant Levels	1	1	1	1	1	1	1	1	1	0.5			9.5	5
12		1	1	1	1	1	1	1	1	1	1	1		11	

Table D.2: Gantt Chart project timeline.



APPENDIX E – Budget

Table E.1: Total project budget.

	Budget				
TEAM	Forge 2.0				
Date	2-Jun-17				
INCOME					
Category	Source	Sought	Committed	Pending	
Grant	School of Engineering	$ 2,000.00	$ 2,000.00		
	Xilinx	$ 2,400.00	$ 2,400.00		
Fundraising	N/A				
	TOTAL	$ 4,400.00	$ 4,400.00	$ -	$ 4,400.00
EXPENSES					
Category	Description	Estimated	Spent	Pending	
Testing	VWR Filter Paper	$ 70.00	$ 82.61		
	Blowtorch	$ 50.00	$ 50.11		
	Butane	$ 24.00	$ 22.49		
	Wood Testing Enclosure	$ 60.00	$ 60.60		
	Galvanized Turbine	$ 30.00	$ 31.00		
	Exhaust Ducting	$ 35.00	$ 34.10		
	Ducting Nozzle	$ 10.00	$ 9.74		
	Arduino Display	$ 15.00	$ 11.99		
	Grove-HCHO Sensor	$ 15.00	$ 11.99		
	Grove Dust Sensor	$ 30.00	$ 31.80		
	Base Shield V2	$ 9.00	$ 8.90		
	Arduino Uno 3 Kit	$ 50.00	$ 48.99		
	Firewood	$ 20.00	$ 8.67		
Prototype	Fully Assembled Stove	$ 700.00	$ -	Courtesy of PWP Manufacturing	
	Air Flow Regulator	$ 100.00	$ -	Courtesy of Cleasby	
	Paint	$ 10.00	$ 9.62		
Travel	Plane Tickets	$ 2,400.00	$ -	On Hold	
	TOTAL	$ 418.00	$ 422.61	$ -	$ 422.61
	Net Reserve (Deficit)		$ 3,977.39	$ -	$ 3,977.39

APPENDIX F – Prototype Assembly

Figure F.1: Full assembly of the Forge 2.0 cook stove.

APPENDIX G – User Manual

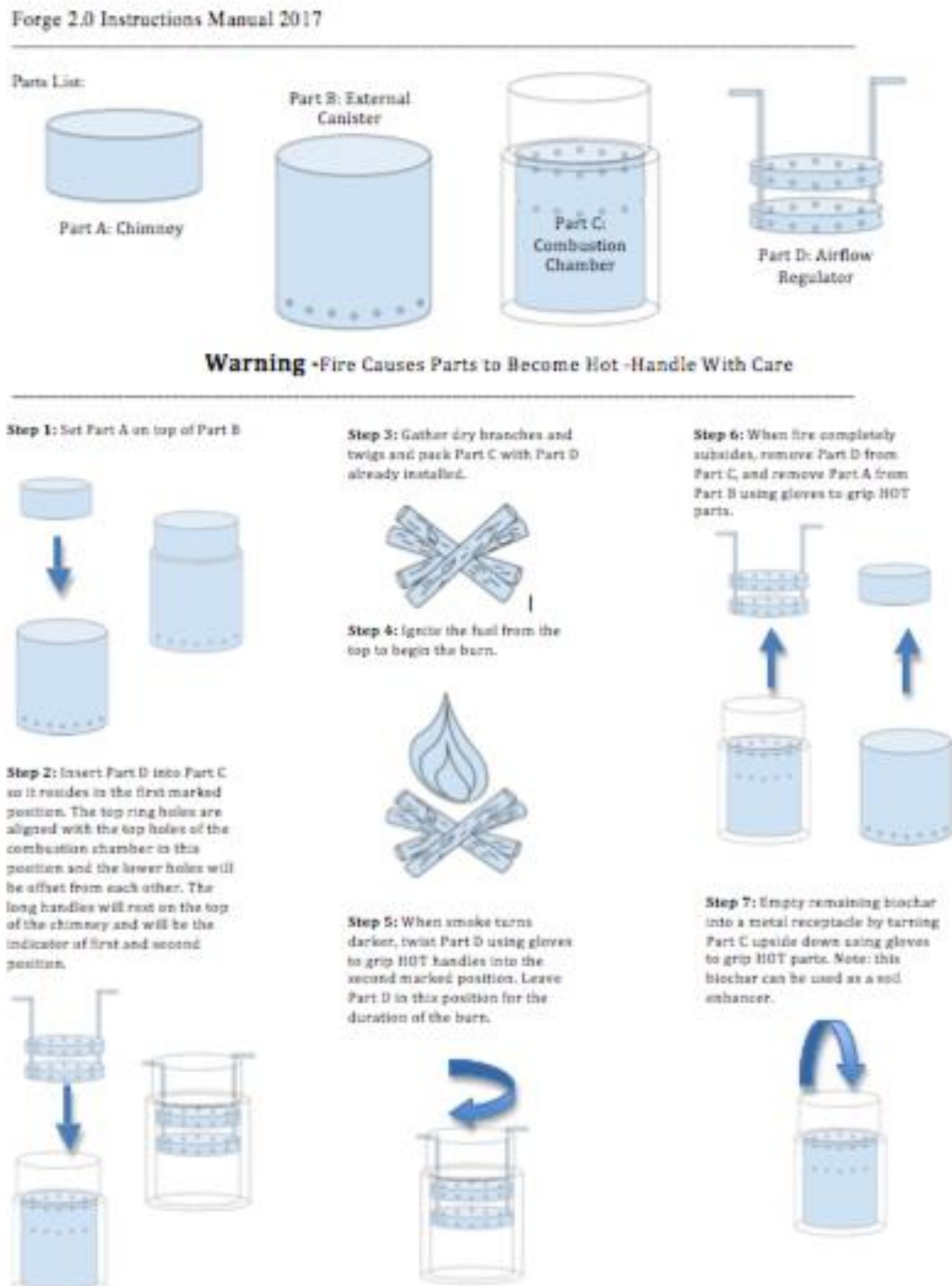
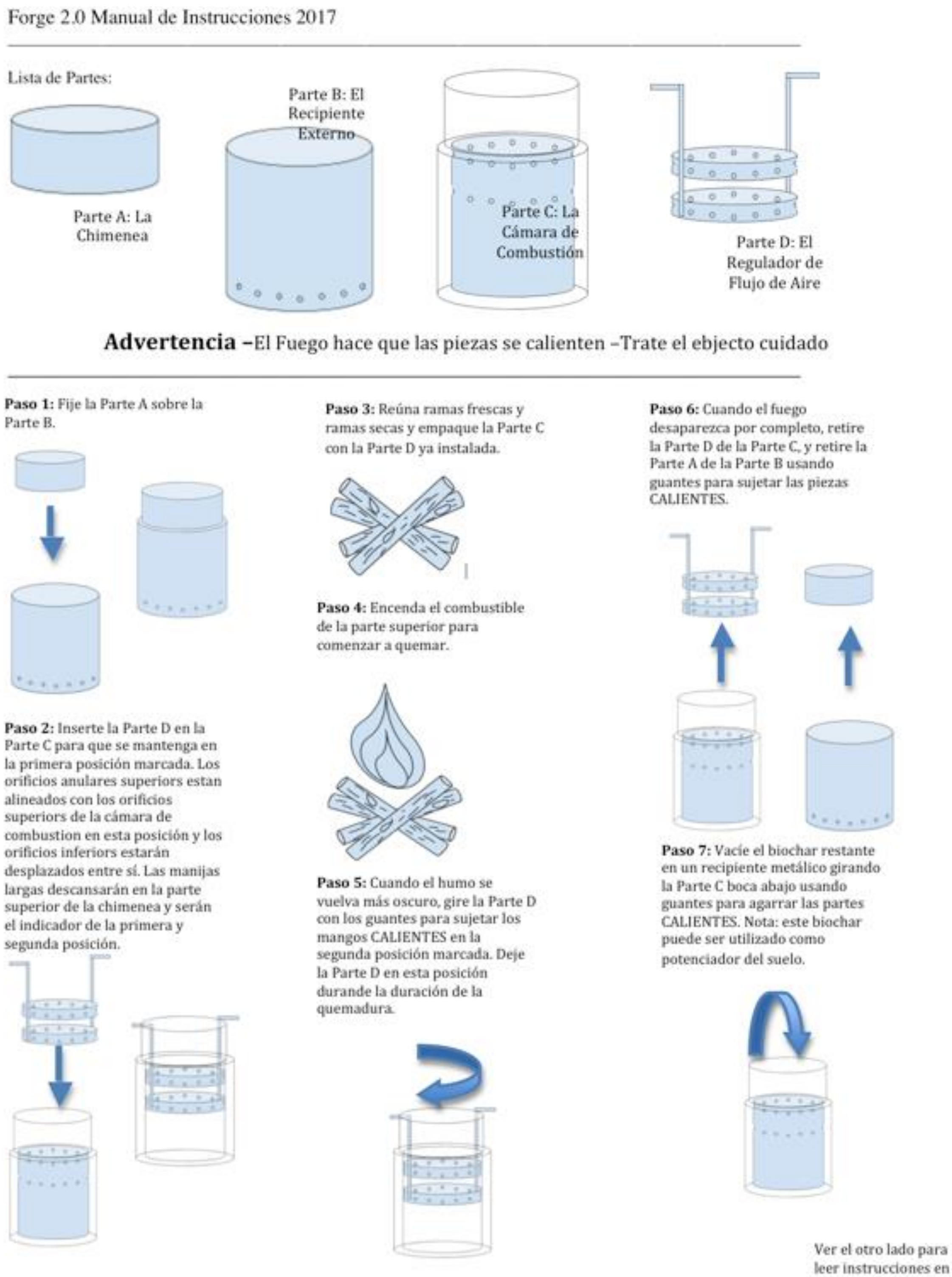


Figure G.1: English User Manual.


Forge 2.0 Manual de Instrucciones 2017

Lista de Partes:

Parte A: La Chimenea

Parte B: El Recipiente Externo

Parte C: La Cámara de Combustión

Parte D: El Regulador de Flujo de Aire

Advertencia –El Fuego hace que las piezas se calienten –Trate el ebjecto cuidado

Paso 1: Fije la Parte A sobre la Parte B.

Paso 2: Inserte la Parte D en la Parte C para que se mantenga en la primera posición marcada. Los orificios anulares superiors estan alineados con los orificios superiors de la cámara de combustion en esta posición y los orificios inferiors estarán desplazados entre sí. Las manijas largas descansarán en la parte superior de la chimenea y serán el indicador de la primera y segunda posición.

Paso 3: Reúna ramas frescas y ramas secas y empaque la Parte C con la Parte D ya instalada.

Paso 4: Encenda el combustible de la parte superior para comenzar a quemar.

Paso 5: Cuando el humo se vuelva más oscuro, gire la Parte D con los guantes para sujetar los mangos CALIENTES en la segunda posición marcada. Deje la Parte D en esta posición durande la duración de la quemadura.

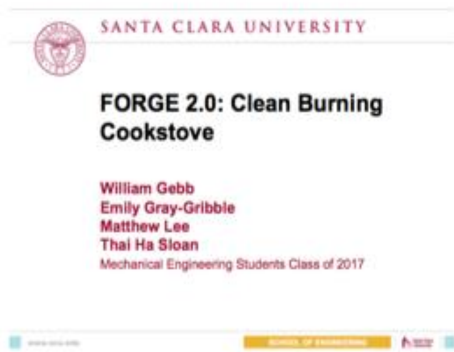
Paso 6: Cuando el fuego desaparezca por completo, retire la Parte D de la Parte C, y retire la Parte A de la Parte B usando guantes para sujetar las piezas CALIENTES.

Paso 7: Vacíe el biochar restante en un recipiente metálico girando la Parte C boca abajo usando guantes para agarrar las partes CALIENTES. Nota: este biochar puede ser utilizado como potenciador del suelo.

Ver el otro lado para leer instrucciones en

Figure G.2: Spanish User Manual.

APPENDIX H - Senior Design Conference Presentation



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Initial Criteria

- Clean-Burning
  - Gasification process
  - Produce minimal to no particulate matter
- Affordable
  - Within reasonable price range for target customers
  - approximately $100
- Highly-Efficient
  - Least amount of fuel necessary
- Safe and Easy to Use
  - Straight-forward user manual w/ all necessary instruction
  - Locally sourced fuels

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Benchmarking Results

Competitor	Weight	Fuel	Max Heat Output	Cost	Efficiency
Team Forge Cookstove	20 lbs	Solid biomass	4.91 kW	$847.37	Unknown
Team Matador Cookstove	99 lbs	Solid biomass	Unknown	$320	Unknown

Forge

Matador

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II. Initial Problem Solution

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Initial Design

System Level Sketch

- Affordable, clean-burning cookstove for developing countries
  - Chemical Functions
    - Biomass gasification
      - Produces thermal energy
      - Reduces pollution
      - Creates biochar
    - Biochar soil-enhancement
    - Stoichiometric air to fuel ratio
  - Mechanical Functions
    - Air to Fuel Ratio Optimizer

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Functional Analysis

Chemical Function: Biomass Gasification

- Local biomass:
  - Thermal energy
    - Cheap
    - Available
- Gasification:
  - Clean and efficient (80-90%)
    - Fast Pyrolysis: Reduction of particulate matter
    - Char Gasification: Reduction of CO_2

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Functional Analysis

Chemical Function: Biochar Soil Enhancement

- Long Term Soil Enhancement:
  - Sustainable soil degradation solution
    - Utilizes local biomass
    - Holds carbon(the main organic component), energy, & nutrients
- Climate Change:
  - Greenhouse gas reduction
    - Increases carbon (CO_2) sequestration by hundreds or thousands of years
    - Reduces nitrous oxide (NO_x) emissions
    - Increases methane (CH_4) uptake

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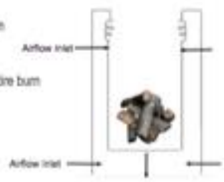
Functional Analysis

Mechanical Function: Air-Fuel Ratio Optimizer

- Optimal Air-Fuel Ratio = 6:1
- System Self Calibration
  - Want optimization of particulate elimination
  - Translate fuel weight to ideal airflow
    - Spring loaded scale mechanism
  - Ensure ideal Air-Fuel Ratio throughout entire burn



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Testing Setbacks

- Temperature Distribution Tests
  - Infrared thermometer & thermal camera
    - Able to get distribution for the steel
    - Maxed out the infrared thermometer
    - No trusted temperature of actual fire
- Particulate Matter Tests
  - VWR filter paper tests
    - Expected to weigh more with particulate matter
    - Always weighed less
  - Grove Dust Sensor Tests
    - Operating temperature range: 0~45℃
    - May not present accurate results

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Realizations

- Regulation of air fuel ratio was impractical
  - Wood is only burning at the surface of the fuel
- Gasification did not last duration of burn
  - Began: 10 minutes into burn
  - Dropped off: 35 minutes into burn
- Aluminum ducting of filter tests
  - Blocked wind
  - Increased air flow

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III. Final Problem Solution

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Final Design

- Affordable, clean burning, gasification-optimizing cookstove for developing countries
  - Chemical Functions
    - Biomass gasification
      - Produces thermal energy
      - Reduces pollution
      - Creates biochar
    - Biochar soil-enhancement
  - Mechanical Functions
    - Chimney
    - Air flow regulation
      - Additional row of secondary inlet
      - Optimizes gasification

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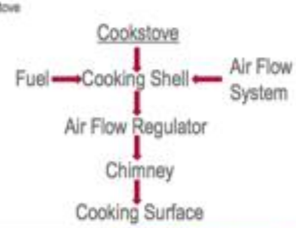
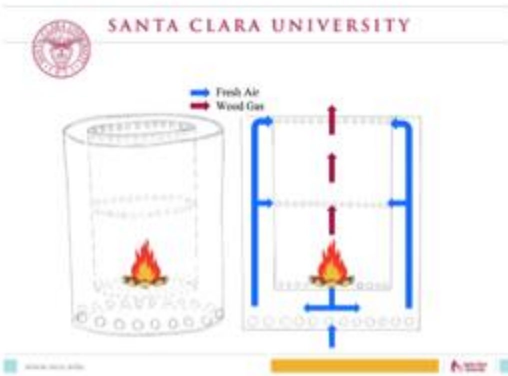
Layout of System-Level Design w/ Main Subsystems

- Main System
  - Entire Cookstove
- Subsystems

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Fresh Air
Wood Gas


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Fuel


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Upper Opening
Upper Secondary Inlets
Lower Secondary Inlets
Primary Inlets
Main Inlets


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Air Flow Regulator


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Chimney and Cooking Surface
Tortilla
Cooking Surface
Chimney


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Functional Analysis
Mechanical Function: Wind blocking Chimney
Decreases time to gasification
Shields flames from wind
Acts as a nozzle
Mechanical Function: Air Flow Regulator
Optimization of Gasification
Maintains high temperature
Increases gasification duration


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Experimental Protocol
Controlled Environment
Windshield
Grind chimney before each test
Weigh fuel (almond wood)
Pack stove with tinder on top for easy ignition
Rate gasification
Note changes in smoke appearance
Video recording
TSI CPC 3007
Weigh biochar


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IV. Testing, Results, and Comparisons


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Testing Burn Progression
Figure 1: Gasification first occurs
Figure 2: Gasification decreases
Figure 3: After mechanism is turned, gasification occurs at lower inlet holes
Timeline
t = 0
(w/chimney) t = 5 min
(w/o chimney) t = 10 min
t = 25 - 30 min
t = 30 - 55 min


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Instruments
TSI Condensation Particle Counter Model 3007
Operation of CPC


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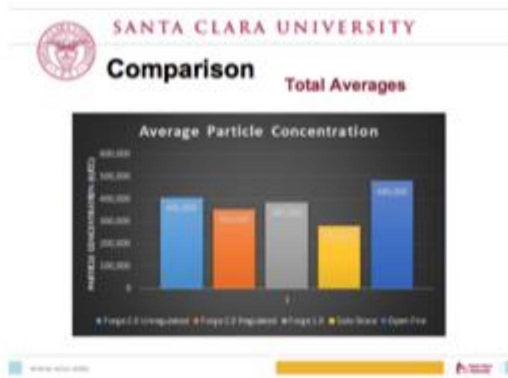
Results
Unregulated vs. Regulated Airflow
405,000
354,000
-Particle concentration data collected during the duration burn without the airflow mechanism in place.
-Both sets of secondary inlets open.
-Particle concentration data collected during the duration of burn with airflow regulation
-Lower secondary inlet holes opened at 1700s



Competitor	Average Particulate Emission (particles per cubic centimeter)	Fuel	Cost
Team Forge 2.0 Unregulated	405,000	Biomass	$700.00
Team Forge 2.0 Regulated	354,000	Biomass	$800.00
Team Forge 1.0	385,000	Biomass	$847.37
SoloStove	279,000	Biomass	Retail Price: $70.00
Traditional Open Fire	480,000	Wood	$0.00

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Comparisons

Initial Criteria vs. Manufactured Results

Initial Criteria		Manufactured Results
Clean Burning	Gasification Process	✔
	Reduced Particulate Matter Emissions	✔
Affordable	Within Reasonable Price Range	
	Approximately $100	
Highly Efficient	Air to Fuel Ratio = 6:1	
	Least Amount of Fuel Necessary	
Safe and Easy to Use	Straight-Forward User Manual	✔
	Locally Sourced Fuel	✔

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V. Future Improvements

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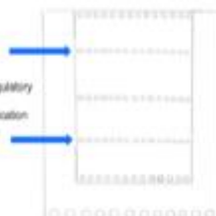
Design Changes

Product Improvement

- Subsystems
  - Combustion Chamber
    - More airflow inlet holes with regulatory mechanism
      - Increase duration of gasification
      - Not a large price increase



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Going Further

- Business Plan
  - 500-600 Stoves
    - Unit price $250.00-$300.00 without profit
    - Loan system
- Implementation
  - Replace all existing non-gasifying cooking methods
    - Reduce the presence of respiratory disease in our targeted area
    - Ease climate change

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Conclusion

- Problem
  - Harmful emissions from biomass cooking
    - Disease plaguing rural Nicaraguan families
- Solution
  - Clean Burning Cookstove
    - Reduce greenhouse emission
    - Reduce respiratory disease
- Future Work
  - Design Improvement
    - Addition of chimney
    - Addition of regulated inlets

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Acknowledgements

Sponsors: SCU Engineering & Xilinx

Susan Kinne, Grupo Fenix

SCU Environmental Science Dept.

PWP Manufacturing

Academic Advisor: Dr. Robert Marks

Course Advisor: Dr. Timothy Hight

Senior Design Conference Executive Summary

Team Forge: Clean Burn Cook stove for Developing Countries
Will Gebb, Emily Gray-Gribble, Matthew Lee, Thai Ha Sloan
May 11, 2017
Email: wgebb@scu.edu, egraygribble@scu.edu , mtlee@scu.edu, tsloan@scu.edu

This presentation provides an overview of the design process for Team Forge 2.0's clean-burning cook stove. This stove is aimed to alleviate respiratory illnesses derived from cooking with biomass. Additionally this cook stove and its byproducts will be designed with the environment in mind and will help mitigate rises in global temperatures as well as combat soil degradation. This cook stove design will use the gasification process to reduce levels of various gases and harmful particulate emissions released when cooking with renewable fuel sources, such as wood and vegetal biomass. The stove is designed for developing countries, such as rural Nicaragua, where our main contacts reside, in order to both alleviate health issues associated with current methods of cooking as well as promote the use of sustainable resources.

Our initial design criteria consisted of an air flow system which would enable the process of gasification as well as the ability to maintain the ideal air to fuel ratio for wood. From testing the previous design team's stove, we made observations which allowed us to come up with alterations that would improve the performance of the stove as an emissions reducer. Upon the implementation of these alterations, we tested our design for the amount of particulate matter in the exhaust.

After many attempts with various testing equipment and setups, we were able to obtain condensation particle counters and used them to gather experimental data for various burn conditions with our design. Ultimately we found that our alterations increased the gasification duration compared to last year's stove, and also decreased the particulate emissions by 10% relative to Team Forge 1.0's design. We believe our design could be further enhanced by the addition of more secondary air inlets with individual air flow regulators.